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DEPARTMENT OF COMMERCE

UNITED STATES BUREAU OF MINES
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SQUARE-SET SYSTEM OF MINING

BY

E. D. GARDNER AND WILLIAM O. VANDERBURG

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SQUARE-SET SYSTEM OF MINING [1]

By E. D. Gardner [2] and William O. Vanderburg [3]

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INTRODUCTION

This paper on the square-set system of mining embodies the results of a special study of the subject made as a part of the Bureau of Mines general investigation of mining methods and costs. Data for the paper were gathered by the authors during visits to mines using square-set mining, from Information Circulars prepared by consulting engineers to the Bureau on mining methods at individual mines, and from articles in the technical press and the Transactions of the American Institute of Mining and Metallurgical Engineers.

The square-set system of mining is very widely applied and is one of the oldest methods in use in the United States. It is mainly employed for extracting relatively high-grade ore in heavy ground. It is also useful in taking out pillars left in mining by other methods. It is used to some extent as an auxiliary method with many underground systems and as an alternate with cut-and-fill, shrinkage, and open-stope methods when heavy ground is encountered. In some cases as much as 50 per cent of the ore may be extracted by square-setting at mines listed as using some other method of mining. A large tonnage is mined yearly by square-setting, principally in the Western States.

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Due to the high cost of timber and the relatively low average production per man-shift, this system generally is not used when the ore can be mined by some other method. It usually is adopted as a last resort. Square-setting, however, has a special field in that orebodies not minable by other methods can be stoped by this system.

As square-set mining was widely known, there was a tendency for years to use the method regardless of its suitability. With the increasing need of economy and the development of other methods, square-setting has been superseded in many mines by cut-and-fill, top-slicing, or sublevel-caving methods.

The term "square-set mining" as used in this paper includes all stoping methods in which the space made by the removal of the ore is timbered with framed sets. The sets usually are square in horizontal section. The stope may or may not be filled with waste rock as stoping progresses.

ACKNOWLEDGMENT

The assistance of C. H. Johnson, assistant mining engineer, Bureau of Mines, in the preparation of this paper is acknowledged.

HISTORY OF THE SQUARE-SET SYSTEM

Prior to 1860, open-stope methods with stulls for casual support accounted for most of the mineral production from underground mines. Attempts to mine large orebodies that required artificial support resulted in disastrous cave-ins and loss of life. The art of mining received a tremendous impetus following the introduction of methods for mining the bonanza orebody which was discovered in 1860 in the Ophir mine on the Comstock lode, Virginia City, Nev. This orebody was phenomenally rich and eventually proved to be 400 feet high, 90 feet wide, and 320 feet long. The mining of this large high-grade orebody taxed the best engineering talent of the time; the problem was finally solved by Philip Deidesheimer.

According to Eliot Lord:[4]

> At the 50-foot level the vein of black sulphurets was only 3 or 4 feet thick, and could be readily extracted through a drift along its line, propping up the walls and roof when necessary by simple uprights and cap-posts. As the ledge descended the sulphuret vein grew broader until, at the depth of 175 feet, it was 65 feet in width, and the miners were at a loss how to proceed, for the ore was so soft and crumbling that pillars could not be used to support the roof as in coal mines. They spliced timbers together to hold up the caving ground; but these jointed props were too weak and ill-supported to withstand the pressure upon them, and were constantly broken and thrown out of place. The dilemma was a curious one. Surrounded by riches, they were yet unable to carry them off and their mass of black sulphurets bade fair to become a white elephant on their hands. The Ophir Company began to wish themselves less fortunate, as their miners narrowly escaped burial day after day in their attempts to stope out the ore.
>
> A young mining engineer, Philip Deidesheimer, was in charge of a quartz mine in Georgetown, El Dorado County, Calif., in the autumn of 1860, when this serious check to the development of the lode occurred. At the request of William F. Babcock, a trustee of the Ophir Company, Mr. Deidesheimer left his California mine and crossed the mountains with a letter from the directors of the Ophir Company,

[4] — Lord, Eliot, Comstock Mining and Miners: U. S. Geol. Survey. Monograph IV, pp. 89-90, 1882.

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authorizing him to inspect the workings of their mines and make such changes in the method of timbering as should seem to him expedient. After examining the vein he designed, in the course of a few weeks, a system of timbering which proved to be exactly adapted to the requirements of the work. Experiments which he had previously made in California gravel and quartz mines furnished the outline of his plan. This was to frame timbers together in rectangular sets, each set being composed of a square base, placed horizontally, formed of four timbers, sills, and crosspieces from 4 to 6 feet long, surmounted at the corners by four posts from 6 to 7 feet high, and capped by a framework similar to the base. The cap pieces forming the top of any set were at the same time the sills or base of the next set above. These sets could readily be extended to any required height and over any given area, forming a series of horizontal floors, built up from the bottom sets like the successive stories of a house. The spaces between the timbers were filled with waste rock or with wooden braces, forming a solid cube whenever the maximum degree of firmness was desired. By adjustments of these sets the ore bodies along the line of the lode were extracted with comparative ease and security.

Most mining methods are evolved slowly and are the result of the combined efforts of a number of minds; Deidesheimer's feat was remarkable in that his system was immediately successful. He died in 1916 at the age of 84, poor and almost forgotten. The Deidesheimer square-set system was never patented.

As an illustration of the care and exactness with which the timbers were placed in the Ophir mine, the excavation made in extracting the bonanza orebody, comprising approximately 11,520,000 cubic feet, was supported entirely by square-sets without filling, the whole presenting as much regularity of appearance as the steel frame of a modern building (see fig. 1).[5] Care was taken to insure that all wedges were tightly driven, allowing the ground no opportunity to start moving. The ore was extracted and the stope timbered in 1861; the stope was filled from the surface in 1862. This stope was probably timbered more elaborately than any stope in the world before or since. Philip Deidesheimer allowed himself a large factor of safety and took every precaution so that his system would not come to grief.

The advantages of the square-set system in mining large orebodies as compared with the other methods of the time were quickly recognized and the idea spread throughout the world. In the Western States the system received its widest application due to the unusual size and richness of the orebodies subsequently discovered and the plentiful supply of timber available.

In the earlier years of square-set mining the erroneous idea was held that timber in heavy ground could support the mass of rock between the back of the opening and the surface. Round timbers 18 to 36 inches in diameter[6] and square timbers of 18 by 18 to 24 by 24 inch[7] size were employed in square-set stopes, but even these massive timbers failed in large stopes. Cave-ins were of frequent occurrence on the Comstock, in Butte mines, on the Mother lode, and on the Homestake belt, in stopes where filling was not used. As it was recognized that any timbering short of solid cribbing could not withstand the slow movements of heavy ground, the sizes of square-set stopes were restricted and the timbering was followed closely by waste filling. This practice made possible the use of smaller timbers.

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[5] – After Storms, W. H., Timbering and Mining: McGraw-Hill Book Co., New York, 1909, p. 192.

[6] – Storms, W. H., The Mother Lode Region of California: California State Mining Bureau Bull. 18, 1900, 154 pp.

[7] – Storms, W. H., Timbering and Mining: McGraw-Hill Book Co., New York, 1909, p. 201.

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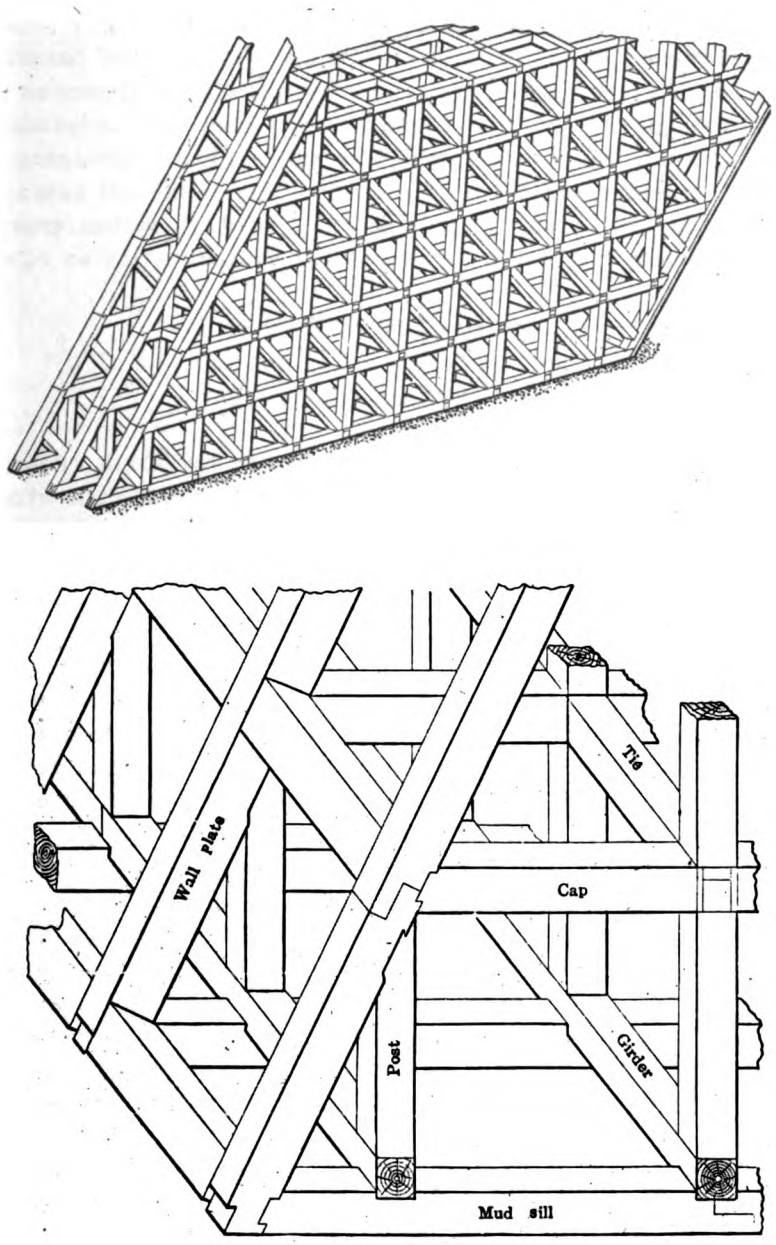

Figure 1.- General view and details of timbering in the Ophir mine, Comstock lode

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The square-set system as originally conceived made use of posts, caps, and girts (ties)—members of the square-sets proper; sills and girders on the floor of each level to permit the removal of the ore directly beneath when advancing a stope upwards from the level below; wall plates, on both hanging wall and footwall, to transmit the weight of the hanging wall uniformly to the structure; and angle braces as auxiliary members of the square-sets to take up the diagonal thrust caused by the weight of the hanging wall. No timber was omitted to make the system as strong as possible. This square-set system as compared with present practice was unnecessarily elaborate. The only members of the square-set system of timbering which are now common to present-day practice are the posts, caps, and girts. The use of waste filling, following closely the extraction of the ore, is largely responsible for the elimination of the angle braces and wall plates. Girders and sills may be omitted; in many cases the floor timbers would be rotted before the ore is attacked from beneath them.

DEFINITION OF TERMS

Square-set Members

The terms employed in different districts to designate the various members of a square-set are sometimes confusing; the following definitions are therefore given as those having the widest application and are those used in this paper.

Brace.—A timber placed diagonally between sets, usually in a direction approximately normal to the hanging wall.

Butt cap.—A short timber used for blocking a line of sets to the footwall. This is not usually considered as a part of a regular set.

Cap.—The principal horizontal member of the set; it is placed across two posts usually in the direction of the width of the orebody.

Cap sill.—A timber framed at one end that is sometimes used in the square-set system to perform the function of a cap, the unframed end resting in a hitch cut into the footwall and the opposite end on a post.

Girt (sometimes called "tie," "girth," or "spreader").—A timber brace connecting two posts horizontally at right angles to the cap and usually in the direction of the length of the orebody. It may or may not be framed.

Girder or sill-tie.—A timber laid on the floor of a level in the direction of the length of the orebody as a part of the base for the square-sets.

Post.—A vertical member of the square-set assembly.

Sill or mudsill.—A timber laid on the floor of a level at right angles to the girder and usually in the direction of the width of the orebody to form with the girders the base for the square-sets.

Sprag.—A round unframed timber used as a girt.

Stringer.—A timber placed horizontally across three posts or the width of two sets.

Wall plate.—A timber placed parallel with the dip of the orebody on either wall and held in position by caps.

Auxiliary timbers used in square-set operations not considered part of the regular sets are blocks, lagging, and wedges.

Square-sets

A square-set is a skeleton framework of timbers forming a hollow rectangular prism. When in place in a stope each edge of one prism is also the edge of a contiguous prism. The timber comprising "one set" standing by itself, disregarding the sills, consists essentially of 8 pieces — 4 posts, 2 caps, and 2 girts. Where the sets follow one another horizontally

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the 2 posts on any side form the side of the adjoining set. In proceeding upwards the top of one set acts as the bottom of the next one above. Sills when used are not considered as constituting a portion of a regular set.

Although one set by itself comprises 8 timbers, the average number of timbers per set decreases with the increase in the number of sets. In a stope four sets wide and six sets long there are on the sill floor 35 posts, 28 caps, and 30 girts, a total of 93 pieces or an average of 3 7/8 pieces per set, not counting any sills or angle braces that may be used.

A set of timbers consisting of 2 posts, 1 cap, and 2 girts is known as a "lead" set. A set consisting of 1 post, 1 cap, and 1 girt added to the lead set or other sets in place is called an "extension" set. "Wing set," "corner set," and "side set" are other names for an extension set and are used as the terms suggest. In ordinary reference to a square-set an extension set is implied.

A "stringer" set is one where stringers are used in place of caps.

Sections and Stopes

"Section" in square-set mining designates a definite block of ground in a stope which is mined according to a prearranged plan.

"Stope" as used in this paper designates a definite part of the workings of a mine which is being operated as a unit. A stope may contain one or several sections. The first floor of a stope is considered here as being the one next above the drift level.

FACTORS AFFECTING THE USE OF SQUARE-SETS

A number of factors must usually be considered in selecting the method for mining any orebody; occasionally one factor will predominate. When square-set mining is being considered, the choice is usually between this method, cut-and-fill, top-slicing, or a caving method. The following factors influence a decision to mine by the square-set system: (1) Grade of ore; (2) physical character of orebody and enclosing rocks; (3) size, shape, and dip of orebodies; (4) effect of ground movement; (5) availability and cost of timber; (6) availability of skilled labor; (7) rate of oxidation of ore minerals; and (8) safety of operations.

Grade of Ore

In mining an orebody, obviously the grade must be such that a profit can be made from stoping it by the method chosen. If the cost of square-set mining approaches or exceeds the value of the ore to be won, square-sets can not be used and a cheaper method of mining must be selected.

A maximum recovery of ore and a minimum admixture of waste from the walls in stoping can be obtained by the use of square-sets. In rich ore the loss inherent to top-slicing or caving may be considerably more than the difference in costs between either of the two methods and square-setting. Selective mining and the maximum sorting out of waste in the orebody can be done in square-set stopes; this advantage may also more than compensate for the added cost of the square-setting over top-slicing or caving.

Character of Ore and Enclosing Rock

With a square-set-and-fill method of mining, the ore can be stoped with less ground opened up at a time than by any other method. In nearly all mines employing the square-set system of mining the ore and the enclosing rocks are altered or broken to such an extent that

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the original rock structure is weakened and unable to support itself, sometimes even over small spaces. In some instances spiling or forepoling is used to hold the ground until a set is stood. Faults, joint planes, gouges, and small quantities of water enhance the tendency of the rock to slough, squeeze, or crumble, if left unsupported. Structurally weak ore and unstable walls usually go together, but this is not always the case.

In high-grade or relatively small-sized ore deposits the character of the ore and that of the enclosing rock are the determining factors in the selection of the square-set method of mining.

With a caving method no open spaces are maintained in stopes after drawing begins, but this system is applicable only to relatively large deposits. Although top-slicing may be used in structurally weak ground, the size, shape, and grade of the orebody must be given due consideration in selecting this method.

In some vein deposits which are nearly vertical or where the walls stand fairly well a choice must occasionally be made between the cut-and-fill method and square-setting. In the cut-and-fill method loose blocks of wall rock or ore may be supported by stulls or occasional cribs until the space is filled. Where this needed support is not extensive the cut-and-fill method usually will be the more economical one to use; however, where the timber required exceeds the amount that would be used by square-setting, the latter method, with its methodical timbering and its added safety of operation, will probably give lower over-all costs. Whenever the walls or ore become too weak for continuing to mine an orebody by the method in use, it usually is an easy matter to change over to square-setting. Should conditions later improve, the original method can again be used.

Size, Shape, and Dip of Orebodies

The square-set system of mining can be used in almost any size, shape, or dip of ore deposit. The orebodies where square-sets are used range from six to several hundred feet in width. The shape may vary from masses of ore with irregular outlines to vein deposits inclosed between fairly uniform walls. The dip of the orebody may vary from flat to vertical.

The square-set system is elastic; it readily adapts itself to irregularities such as occur where the ore widens out on one floor, pinches on the next, and on the third is of high grade but includes considerable waste. A caving or a top-slicing method is not applicable to an extremely irregular orebody, as waste would be mixed with the ore and probably some ore would be lost.

Square-setting is particularly adapted to mining irregular orebodies or stringers of ore in soft ground. Under such conditions the ore is usually mined as it is opened up. It can be thoroughly prospected and followed wherever it goes and at the same time mined by the square-set method. Another advantage of square-set stoping is that the walls of the orebody can be prospected or stringers followed by subdrifts as stoping in the main orebody progresses with less expense than with any other method. This factor is sometimes important enough to cause square-setting to be used rather than top-slicing.

Square-sets may be used as scaffolds on which the men may stand to drill rounds in flat, tubular, or irregular high-grade deposits where neither the walls nor ore requires support. In such cases the ore may be allowed to drop to the track level, to be shoveled into cars by hand, or the top of the sill floor may be lagged over to form "chinaman" chutes for loading the cars. Temporary chutes may be built if the orebody is over two sets high. The square-sets may be removed and reused after a stope is finished.

Such orebodies as previously mentioned are not amenable to mining by a regular shrinkage method; leaving the broken ore in the stope to permit the miners to reach the back interferes with the advance of the stope. Moreover, in such cases the ore usually is removed as broken to keep up the regular production of the mine.

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Effect of Ground Movement

Although in square-set stopes some settling may occur in the fill, it is less than with other methods of mining. To prevent movement of ground in a shaft or other underground working over or near stopes a square-set method may be used rather than one giving a lower mining cost. Square-setting may also be used, rather than caving or top-slicing, if it is necessary to prevent surface subsidence.

Availability and Cost of Timber

From 10 to 30 board feet of timber per ton of ore is required for minirg by the square-set method, depending upon the kind of sets used and the weight of ground to be held. The cost of timber is a large item in the mining cost. Where timber is locally available at a low price a square-set method might be the most economical ore to use, whereas if mines were remote from a timber supply another method would be employed.

Square-set mining has been displaced at many places due to increasing prices of timber, as, for example, in the Michigan copper mines.[8] To give better support to the hanging wall as well as to permit extraction of more ore by leaving less unmined ground in pillars, square-sets were formerly employed in this district, particularly in mining the conglomerate lode. This method of support became very popular and was extensively used until the cost of timber and its framing and placing became prohibitive, whereupon square-setting yielded to the present method of timbering with stulls.

Sources and Cost of Waste Filling

In most square-set operations the orebodies are more or less irregular and a relatively large amount of waste is obtained from sorting and from exploration and development work in proximity to the main orebody. The waste obtained in this work can be used to fill the stopes at low cost; a saving is also effected in the disposal of the waste, as it does not have to be hoisted to the surface. Where waste for filling must be broken from crosscuts or chambers driven into the walls, this extra work increases the stoping cost.

Availability of Skilled Labor

Workmen of greater skill are required to mine by square-setting than by some other methods of mining. The availability of such labor may be a factor when considering the use of this method of mining.

Rate of Oxidation of Ore Minerals

Some copper and iron sulphides in broken ore oxidize or tarnish when left to stand in stopes for any length of time. This alteration of the minerals reduces the percentage of recovery when the ore is treated by the flotation process. Ore mined by square-setting is usually brought to the surface soon after being broken; therefore, when oxidation of the minerals is a factor, this method is to be preferred to either the caving or shrinkage methods of mining.

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[8] - Crane, W. R., Mining Methods and Practice in the Michigan Copper Mines: Bull. 306, Bureau of Mines, 1929, p. 89.

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Safety of Operations

Square-sets are generally used in heavy ground. The sets are immediately placed to support the ground, thus protecting the workmen from falling rock or ore. The close timbering in square-set stopes affords better protection to the workmen than can be provided in the cut-and-fill and shrinkage systems of mining in similar ground. On the other hand, the relatively large amount of timber used in square-setting introduced an added fire hazard. Moreover, accidents may occur in the handling of this timber in the mine and in the use of axes and saws in standing the sets.

Summary

The relatively high cost of stoping by the square-set method may be offset by the following advantages:

1. Its adaptability to mining irregularly shaped orebodies in caving ground.
2. A maximum recovery of the ore.
3. A minimum admixture of waste with the ore mined.
4. A minimum of subsidence and the consequent preservation of the original surface or nearby workings.
5. The facility with which it lends itself to prospecting of the walls by intermediate drifts during stoping operations.
6. Its adaptability to mining irregular deposits as they are developed.
7. Security of workmen, and minimum danger of loss of a stope by caving.
8. Although of minor importance, the mining of the ore in regular rectangular prisms is a convenience in keeping engineering and cost records.

SQUARE-SETS

Timber is more satisfactory than any other structural material for supporting heavy ground in stopes. It is easily framed, readily replaced if broken, and gives warning before failure. The blocking of sets will be compressed before failure will occur in the main members. By removing the material immediately adjacent to the timber, pressure can also be relieved or "eased" more readily than with other methods of support.

The life of the timber can be prolonged by the use of preservatives, but in square-set operations where the mechanical life of the timber is less than its organic life there appears to be no economy in treating the timber.

Timber Used

In the untimbered areas of the Western States Douglas fir (also known as Oregon pine) from Washington and Oregon is mostly used for mine timbering. Where timber is locally available other species are used for square-sets, although Douglas fir may be shipped in for shaft and other more-or-less permanent construction.

At Butte, Mont., lodgepole pine, a short-lived timber, is used largely for square-sets. Yellow pine, tamarack, and spruce are used for drift timbers and chutes and to some extent for square-sets.

In the Coeur d'Alene district of Idaho, mountain fir, yellow pine, tamarack, spruce, and hemlock are used for square-set timbers.

In smaller districts other species of locally available timber are used, such as cedar, redwood, and oak. In the Jarbidge, Nev., district, cottonwood, the only timber growing near the mines, has proved satisfactory for lining chutes.

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Arizona yellow pine is used in the Jerome district of Arizona. Douglas fir is used in the other important districts of the State for square-set timbers; it is also shipped in for most of the Utah and Nevada mines.

Table 1 gives the relative strengths of certain species of timber used in mines.[9]

Table 1.--Relative strength of certain timbers used in mines

Common name	Weight per cubic foot, pounds		Relative shrinkage, (1) comparative scale	Composite strength values, comparative scale			
	Green	Dried to 12 per cent moisture		Bending strength	Compressive strength (end-wise)	Stiffness	Hardness
Cedar, Port Orford	36	29	106	82	90	168	48
Douglas fir (coast type)	38	34	121	90	107	181	59
Hemlock, western	41	29	120	74	84	144	50
Larch, western	48	36	129	89	104	153	64
Oak, canyon live	71	54	158	110	127	159	181
Oak, chestnut	61	46	162	102	94	166	90
Pine, lodgepole	39	29	114	67	74	128	41
Pine, long-leaf	50	41	124	106	123	189	76
Pine, western yellow	45	28	97	65	69	112	41
Redwood	55	30	65	90	104	134	59
Spruce, Engelmann	39	23	102	55	57	100	32

1 - Volumetric composite value from green to oven-dried state based on dimensions when green.

Other qualities besides strength are desirable for mine timbers, such as light weight, resistance to decay, resistance to abrasion, and freedom from warping in seasoning. Douglas fir has all of these qualities to a high degree and is admirably suited for square-sets. Other species may have undesirable qualities and still be used because of availability and lower cost. For instance, lodgepole pine is relatively weak and is likely to decay within a year under the conditions existing in the average mine; yet it is often employed because of its low cost and ready availability. Hemlock twists and warps as it seasons, and Port Orford cedar and redwood, although resisting decay to a high degree, are easily abraded by falling rock.

The choice of the kind of timber to use is governed mainly by cost. The undesirable qualities of locally available timber are usually balanced against the high cost of imported Douglas fir. In moderately heavy ground that will be mined within a year the local timber may be the most economical to use, whereas in heavy ground that must be kept open for a longer period the Douglas fir may be the less expensive.

The quality of timber bears an important relation to its strength. A poor quality of an inherently stronger species may prove to be less satisfactory than a good quality of an inherently weaker species of timber.

Seasoned timber should be used whenever practicable, as the strength of green timber is only about one-half the strength of the same timber when absolutely dry.[10] Although it

9 - Markwardt, L. J., Comparative Strength Properties of Woods Grown in the United States: U. S. Dept. of Agriculture, Tech. Bull. 158, Feb., 1930, 38 pp.

10 - Nelson, John M., Prolonging the Life of Mine Timber: U. S. Forest Service Circular 111, 1907, p. 11.

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may not be practicable for most mining companies cutting their own timber to hold it until absolutely dry, peeled timbers will dry out sufficiently for most purposes in from 2 to 4 months. Round timber that is shipped any distance should be peeled and seasoned. The saving in freight due to the lighter weight of the timber usually more than compensates for the labor cost of peeling and the interest on the capital invested during the seasoning period.

The use of squared timber for square-sets in place of round is largely a question of economy in transportation. The mines close to the timber supply use round timbers, while those at a greater distance generally buy the squared stock.

Size of Sets

Standard-sized sets are used at most mines and the size of the timber for the members of the set varies to fit different ground conditions. The cross section and height of the sets are usually chosen for average conditions.

The space required for a set should not exceed that which can be drilled and blasted in a shift. Usually, however, in ground requiring square-setting this is not a consideration; the volume of the round generally must be limited to the space that can be timbered by a set. Relatively small sets have an advantage in ground that will support itself only over short spans. A further advantage exists in moving ground, as replacing broken timbers in large sets is more expensive than in small ones.

Obviously, a set must be of such size that the miners or shovelers have sufficient room in which to work. The distance between caps should not be so great that lagging of ordinary strength will be broken by the top pressure between the caps. In narrow, flat-dipping beds or veins relatively short posts would probably be the best to use, while in vertical workings longer posts would be more economical.

Increasing the size of the timber permits the use of larger sets. However, an economic balance will exist between the volume of the set and the size of the timber. With the same size of timber, timbering costs per ton are less with large sets than with small ones. As large timbers are expensive and difficult to handle and place in position, the advantage in cost due to the use of larger sets may be lost if heavier timbers must be used.

At the Bunker Hill and Sullivan mine the sets are usually 5 feet wide, but in parts of stopes that stand relatively well the sets may be 10 or 15 feet wide, in which cases longer caps are used and either one or two lines of posts and girts are omitted. At some mines where the caps and posts are framed alike, caps may be used for posts in heavy ground.

As shown in Table 2, the height of single sets center-to-center ranges from 6 feet 2 inches to 9 feet. The plan ranges from 4 feet 9 inches by 5 feet to 7 feet 4 inches square in cross section. Stringer sets range in size up to 5 by 16 feet in plan and from 6 to 8 feet 7 inches high.

Size of Timber

The increasirg scarcity of timber, combined with a more judicious use of waste filling and with refinements in mining practices, has resulted in the use of smaller sizes and poorer qualities of timber for square-setting than formerly was the case. The reduction in the quantity of timber used has been partly brought about also by standardization in the lengths and sizes of timbers.

The size of the timber used in any particular case depends upon the size of the section, the amount of ground open at any one time, and the rate at which the ore is mined. Where the sets are promptly filled with waste the timbers may be of more moderate dimensions, as in this case the support afforded by the timbers is more or less temporary.

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It is difficult, if not impossible, to estimate with any degree of accuracy the size of timbers required to support any particular mine opening where the rock will not support itself, as too many variables are involved. Experience in each particular place usually must be the guide in selecting the size of timbers to be used. Jointing planes, fissuring, faults, and swelling of the ground by oxidation and absorbtion of air or moisture, as well as the pressure exerted from the superincumbent rock are all factors which have an influence upon the weight that must be withstood by the timbers. In some stopes, timbers are seen to be taking weight a few hours after being placed in position, and if filling is not used they require renewal within a short period. Fortunately, in most mines the ground movement is slow and plenty of time is afforded to fill the mined-out portions of the orebody with waste before collapse occurs.

The timber should be large enough, and only large enough, for the duty required of it. Where pressure of equal intensity is to be expected from three directions, all members of the set would be made of the same-sized stock. In mining in a vein, pressure would be expected from the ore above and walls at the sides. In this case the girts would be made of smaller-sized material.

Where side pressure is the greatest, posts can be of smaller stock than caps; conversely when the top pressure is the most important, posts should be of larger timber than the caps or girts.

Dimensioned timbers used for sets range from 6 by 6 to 12 by 12 inches. Round timbers vary from 6 to 20 inches in diameter. Round posts are usually placed with the butts upward to give the greatest bearing surface to the caps and girts.

Table 2 shows the sizes of timber used in a number of different types and sizes of sets at representative mines.

Framing Square-sets

Square-sets usually are framed by gang saws. This method of framing is less expensive than framing by hand and on the average is just as accurate. The sets may be framed at the mine or at the saw mills before shipment. When done at the mine the work can be supervised by the mine management and waste timber can be used for blocking or wedges. Framing at the saw mills, however, permits a saving of freight charges on the timber of sets, and possibly a saving in the quantity of timber purchased. At the mine of the Consolidated Coppermines Co., when old timber is used for blocking, a saving of 17 per cent in the quantity of timber purchased per set was made by having the sets framed at the saw mill.

In the early days of square-setting, when timbering was not immediately followed by filling, the idea prevailed that for the sets to carry the weight of the ground each member of the set as stood had to be absolutely plumb or horizontal. Therefore, a large number of specially framed members was required in heavy ground. Where the sets already installed had been forced out of alignment by ground pressure, some of the members were cut at different lengths. Moreover, to keep the posts vertical the ends were framed unsymetrically. This changing of the position of the horn on a post was called "flirting."

In present practice, in which filling usually closely follows breaking, standard timbers are used with little or no further cutting or framing. Where special framing may be required under unusual conditions the miners or timbermen themselves alter a standard member to fit as nearly as possible, rather than send specifications for a special timber to the framing shed at the surface as was formerly done. The virtual elimination of specially cut timbers has reduced timbering delays and thus lowered mining costs.

In any system of framing, each member of the set should be interchangeable with another of its kind. To insure the maximum strength in a square-set as a whole, all joints should

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Table 8.- Types and sizes of square-sets

Figure No.	Name of mine or set	Location	Type of framing	Section, inches (rd = round)			Over-all lengths of members, feet, inches			Center-to-center dimensions, feet, inches			Saw cuts, per set1/	Ore per set, cubic feet2/	Timber per set,2/ board feet	Timber per cubic foot of ore, board feet
				Post	Cap	Girt	Post	Cap	Girt	Vertical	Capwise	Girtwise				
2,A	Cananea set	Sonora, Mex.	Post-butting	10x10	10x10	8x10	7-4	4-10	4-10	7-4	5-3	5-3	24	302	133	0.44
-	Goldfield set	Goldfield, Nev.	do.	8x8	8x8	6x8	7-4	4-7	4-7	7-4	5-0	5-0	24	163	68	.45
-	Tintic Standard mine (old type)	Dividend, Utah	do.	8x8	8x8	8x8	7-0	5-8	5-8	7-0	6-0	6-0	24	222	98	.39
-	Homestake mine	Lead, S. Dak.	do.	12x12	12x12	11x12	8-3	5-6	5-6	8-3	6-0	6-0	40	397	286	.76
-	Bunker Hill and Sullivan (square posts)	Kellogg, Idaho	do.	10x10	8x10	8x10	7-10	4-8	4-8	7-10	5-0	5-0	24	196	127	.65
2,B	Bingham set	Bingham, Utah	Cap-butting	9x10	10x10	6x10	6-8	5-0	4-4	7-4	5-0	5-0	36	163	114	.68
3,A	Portland post-butting set	Cripple Creek, Colo.	Post-butting	10x10	10x10	10x10	7-3	5-4	5-4	7-3	5-8	5-8	40	235	149	.64
3,B	Burlingame set	Butte, Mont.	do.	10x10	10x10	10x10	7-0	5-0	4-6	7-0	5-6	5-0	40	195	138	.71
-	Vulcan mine	Vulcan, Mich.	do.	12x12	12x12	12x12	7-10	7-0	6-7	8-0	7-5	7-0	24	416	257	.62
-	Bunker Hill and Sullivan (round posts)	Kellogg, Idaho	do.	10-14rd	8x10	8x10	8-10 or 9-10	4-8	4-8 or 5-8	8-10	5-0	5-0	24	171	127	.74
3,C	Pecos mine	Terrero, N. Mex.	do.	10-12rd	11-13rd	8-10rd	6-7	4-8	4-8	6-7	5-0	5-0	48	166	121	.73
-	Coeur d'Alene set	Wallace, Idaho	do.	10-12rd	8x10	8x10	8-0 or 9-10	4-8	4-8 or 5-8	8-0	5-0	5-0	24	200	126	.63
3,D	Center Star mine	Rossland, B. C.	do.	12-15rd	12-15rd	12-15rd	8-0	4-10	4-10	8-0	5-4	5-4	56	327	210	.65
4,A	Butte set	Butte, Mont.	Cap-butting	10x10	10x10	6x10	7-0	5-0	4-6	7-6	5-0	5-0	32	188	123	.65
-	Butte set	do.	do.	12x12	12x12	8x12	7-0	5-0	4-4	7-6	5-0	5-0	32	192	179	.93
-	Copper Queen mine	Bisbee, Ariz.	do.	10x10	10x10	5x10	7-5	5-0	4-7	7-10	5-0	5-0	32	196	125	.63
-	Aspen set	Aspen, Colo.	do.	10x10	10x10	10x10	6-6	5-4	4-10	7-0	5-4	5-4	40	199	139	.70
4,B	Ruth mine	Ruth, Nev.	do.	10x10	10x10	10x10	7-3	5-6	5-3	7-8	5-6	5-8	40	239	149	.62
4,C	Esperanza set	Esperanza, Mex.	do.	8x8	8x8	8x8	7-6	5-0	4-6	8-0	5-0	5-0	24	200	91	.45
4,D	Richmond mine	Eureka, Nev.	do.	12x12	12x12	10x10	6-2	5-0	4-0	6-10	5-0	4-9	48	161	168	1.04
-	Calumet & Arizona mine	Warren, Ariz.	do.	10x10	10x10	10x10	7-4	5-0	4-6	7-10	5-0	5-0	40	196	140	.71
4,E	Tintic Standard mine	Dividend, Utah	do.	9x10	10x10	6x10	6-4	6-0	5-4	7-0	6-0	6-0	28	268	184	.69
-	Park Utah mine	Keetley, Utah	do.	9x10	10x10	6x10	6-8	5-0	4-4	7-4	5-0	6-0	28	188	113	.68
-	Magma mine	Superior, Ariz.	do.	10x10	10x10	8x10	6-0	5-0	4-6	6-8	5-0	5-0	40	167	122	.73
-	United Verde mine	Jerome, Ariz.	do.	10x10	10x10	10x10	6-7	5-6	4-11	7-2	5-6	5-6	40	217	143	.65
-	United Verde Extension mine (two sets)	do.	do.	(10x10 (8x8	(10x10 (8x8	(10x10 (8x8	(7-7 (7-9	(5-6 (5-6	(4-11 (5-1	(8-2 (8-2	(5-6 (5-6	(5-6 (5-6	(40 (40	(247 (247	(150 (98	(.61 (.40
-	Leadville set	Leadville, Colo.	do.	10x10	10x12	7x12	6-3	6-10	5-3	7-0	6-10	5-10	36	279	157	.56
-	Tonopah Extension mine	Tonopah, Nev.	do.	10x10	10x10	10x10	7-6	6-0	6-0	8-1	6-0	6-7	40	319	163	.51
-	Eureka set	Eureka, Nev.	do.	12x12	12x12	12x12	6-6	5-8	4-4	7-0	5-8	5-0	40	194	196	1.01
-	Portland cap-butting set	Cripple Creek, Colo.	do.	8x8	8x8	8x8	6-6	5-0	4-6	7-0	5-0	4-11	44	178	85	.49
4,F	New Idria mine	New Idria, Calif.	do.	10x10	8x8	8x8	6-6	5-0	4-6	6-11	5-0	4-10	48	167	105	.63
-	Pilares mine	Sonora, Mex.	do.	12rd	8x10	6x10	7-6	5-0	4-6	8-0	5-0	5-0	32	200	127	.64
-	Arizona Copper Co. mine	Morenci, Ariz.	do.	12rd	8x8	8x8	6-9	5-0	4-7	7-8	5-0	5-0	40	179	115	.64
5,A	Page mine	Kellogg, Idaho	do.	10rd	10rd	5x8	6-6	5-0	4-7	6-11	5-0	5-0	32	173	91	.53
5,B	Argonaut mine	Jackson, Calif.	do.	14-18rd	12x12	8-12rd	7-0	5-4	4-0	7-10	5-4	5-0	12	209	208	1.00
-	Rossland set	Rossland, B. C.	do.	12-20rd	12-16rd	12-16rd	8-2	5-4	4-4	8-10	5-4	5-6	44	235	261	1.11
-	Clark mine	Butte, Mont.	do.	10-14rd	10x10	7-8rd	6-7	5-7	4-5	7-0	5-7	4-10	40	189	127	.67
5,C	Black Rock mine	Butte, Mont.	do.	10-12rd	10-12rd	10-12rd	7-7	5-10	5-5	8-0	5-10	5-10	40	272	168	.55
5,D	Anaconda Rocker set	Butte, Mont.	do.	14rd	14rd	12rd	7-5	5-4	5-0	7-9	5-4	5-4	3/ 112	220	211	.96
-	Bendvis mine	Burma	do.	10rd or larger	10rd or larger	8rd or larger	7-0	5-6	5-2	7-4	5-6	5-6	80	222	105	.46
5,E	Brunton bevel set	Butte, Mont.	do.	16rd	14rd	14rd	7-10	7-10	5-5	8-3	7-10	5-10	36	377	301	.80
-	Brunton square and bevel set	do.	do.	16rd	16rd	16rd	7-10	5-10	5-10	8-3	5-10	6-3	64	301	387	1.09
5,F	Chillagoe mine	Queensland, Australia	Cap-and-girt butting	12rd	10rd	10rd	6-0	6-2	6-2	6-2	6-2	6-2	40	236	137	.58
-	Umsarra V-framed set	Candor, N. C.	Cap-butting	10rd	10rd	10rd	7-2	6-0	6-0	7-7	6-0	6-0	56	273	125	.46
6	Moore diagonal set	Tonopah, Nev.	do.	6x10	8x10	8x10 or 6x10	8-5	7-6	5-4	8-0	7-6	5-11	40	365	170	.48
7,A	Silver King stringer set	Park City, Utah	do.	8-10rd	8x8	6-8rd	6-6	10-0	4-4	6-10	10-0	5-0	None	342	4/ 150	.44
-	Silver Hill stringer set	do.	do.	8x8 or 8-10rd	8x8	4x8 or 6-8rd	6-6	10-0	4-4	6-10	10-0	5-0	16	342	4/ 146	.43
7,B	Morning mine	Mullan, Idaho	do.	12-16rd	12-16rd	10-12rd	8-0	8 to 16	4-0	8-7	8 to 16	5-0	4	510	5/ 445	.87
-	Hecla and Star mines	Burke, Idaho	do.	12-16rd	12-16rd	3x10 or 6x10	8-0	8 to 16	4 or 9	9-0	8 to 16	5 or 10	None	540 or 1,080	5/ 402 or 472	.75 or .44

1/Right-angle cuts are counted as two cuts, beveled cuts as one. Slabbing cuts are not counted. Where sets are framed underground, framing cuts are not counted. A set consists of one post, one cap, and one girt. 2/Based on center-to-center dimensions of sets. 3/The board-foot content of round timbers is calculated on the basis of the total volume of the timbers. The formula used is: Bd. ft. = $0.06545\ d^2l$, in which the diameter (d) is expressed in inches, and the length (l) in feet. 4/More or less, depending on size of timber. 5/In stull or stringer sets five timbers to a set; i.e., two posts, one cap, and two girts.

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be cut on a true plane so that all members will have an even bearing upon each other.

Symmetrical, simple joints are generally desired, as the framining is less expensive and less labor is required to stand the sets in place than with elaborate or unsymmetrical framing. Faulty design of the joints may cause the sets to "jackknife" when pressure is exerted upon them. A framining of the joints that can be made with the least expense and that holds the different members of the set in a fairly right-angular position under pressure is desirable.

With square timber the planes of the joints are at right angles; with round timbers the joints are either square or beveled. The bevel or mitre joint is harder to frame and the sets are more difficult to block and wedge in position than is a right-angled framing. The present practice tends toward the abandonment of the bevel joint.

In designing a square-set for any particular mine the following factors must be conidered: (1) Amountof pressure to be withstood; (2) length of time sets will remain open before filling; (3) direction of maximum pressure; (4) whether framing is by hand or power saws—with hand framing a simple joint is usually the most economical; (5) efficiency of the joint under eccentric loading; (6) ease of handling the timbers and placing and blocking the set.

The principal features of square-sets have not varied greatly since the system was invented in 1860; however, framing details do vary at different mines, although the advantages or disadvantages of the respective variations are not always readily apparent and remain largely a matter of opinion.

A standard method of framing is usually, but not always, followed at each mine or group of mines under the same management. One method of framing may be favored in one district and another method in some other district under similar conditions.

As the crushing strength of timber is greatest endwise of the grain, square-sets are theoretically framed so that those members of the set butt together which lie in the direction of the highest pressure. With three lines of timbers meeting at right angles, it is obvious that with square framing only one line can be made continuous. Where the pressure is from the side walls the caps are made to butt against each other, and where the greatest pressure is caused by the vertical weight of the ore the posts are placed end-to-end. In the original design of the square-sets at the Ophir mine the posts were made to butt, as the greatest weight came from the ore above.

The methods used for framing joints may be grouped into two general classes or types: (1) Post-butting joint type (see fig. 2, A), where the maximum pressure on the sets is from the weight of the ore above; and (2) the cap-butting joint (see fig. 2, B), where the maximum pressure on the sets is from the sides.

Although the post-butting type has an advantage under some conditions and continues to be used, present practice tends toward the adoption of the cap-butting type of framing. Where both side and top pressures are encountered the cap-butting type is preferable, as the long horn on a post of a post-butting set is a point of weakness. The strength of a post is proportional to the area of cross section over which the load is distributed. If a post has an area of 12 by 12 inches and the bearing on its end is confined to a 6 by 6 inch area, the timber will begin to fail as soon by crushing as though its full cross section were only 6 by 6 inches; consequently, the post-butting joint is not as strong as the other. The pressure coming on the horn of a post has a tendency to split and spread it and in so doing may force the caps and girts from their seats on the post. Furthermore, the bearing area of the horn is small laterally, and if the horn is crushed when pressure comes upon it the sets may be forced out of alignment. These objections are largely eliminated with the cap-butting joint, because where the caps butt against each other the horn or tenon on the post is short and has a relatively large cross-sectional area; consequently, when the caps are compressed

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the weight is carried over the greatest cross section of the post instead of on the long, narrow horn. A joint with the post butting also generally has the disadvantage of a relatively deep mortise at the top; this mortise usually becomes filled with fine ore from blasting, so that if it is not entirely cleaned out an imperfect joint results when the next post above is placed. Moreover, miners are disposed to cut off the horn at the bottom of the post instead of cleaning out the hole to fit the horn.

In framing square-set joints a relatively larger proportion of the original timber is cut away in making the horns for a post-butting set than in forming the tenons on a cap-butting set. Consequently a little more timber is required for a set of the former type. However, as shown in Table 2, fewer cuts with the saw are required in framing a typical post-butting set; this extra framing for a cap-butting set about offsets the saving in timber over the other type of set.

In the post-butting type of framing the horns usually are the same length on each end of the posts and both ends are framed symmetrically. The type of framing shown in Figure 2, A, is more or less standard for the post-butting type of set; the horns are in proportion to the different-sized timbers used. Similar sets are used at the Homestake mine and have been used at Goldfield and the Tintic Standard mines (Table 2). Variations of the standard method, however, are used at some important mines. At the Bunker Hill and Sullivan mine the top horn is 7 inches long and the bottom one 3 inches long. The framing shown in Figure 2, A, is relatively simple--the caps are simply unframed, squared timbers. This form of framing is followed at most places where the horn type of set is used. Exceptions are shown in Figure 3, A, and B. In Figure 3, A, the tops of both cap and girt are dapped 1/2 inch. In Figure 3, B, a 2-inch dap is used at both top and bottom.

The horn in most cases is one-half the diameter of the post or one-quarter of the cross section. At the Bunker Hill and Sullivan mine and the Portland mine (fig. 3, A) a horn 4-inches square is used on a 10-inch post, and at Goldfield a 5-inch-square horn was used on an 8-inch post. The horn on the Burlingam set (fig. 3, B) is 6 inches square on a 10-inch post. The added bearing space needed for the caps and girts is supplied by top and bottom daps. The framing of the joints of the sets listed in Table 2 at the Homestake, and the old type set at Tintic Standard are similar to the Cananea set (fig. 2, A).

Formerly, in sets of the post-butting type a space of 1 inch or more was sometimes left between the ends of the posts to allow a certain amount of "give" when pressure was exerted upon the sets. In recent times such a practice has been largely avoided, as it is considered at most places that the squeeze space permits considerable movement so that it becomes difficult to keep the sets in alignment. The practice, however, is still continued at the Pecos mine (fig. 3, C).

Another abandoned practice once followed at a few places where heavy top pressures were to be withstood was to cut the posts for the sets in the center of a stope 1 or 2 inches longer than the length required to make a rectangular set. The theory was that as the sets took weight, the posts would be pushed down in line and thus make a square joint and an even floor. Experience, however, proved that no advantage was gained, and the practice has been discontinued.

The same type of framing is generally used when round timber is substituted for square stock in any of the members of the set. Round posts are more often used than round caps or girts on account of the desirability of having a flat surface on which to lay floors. When round caps are employed they are usually slabbed flat on the upper side.

Round posts generally are used at the Bunker Hill and Sullivan mine. The framing details are similar to those previously described for square timber, at the same mine. The caps and girts are set on the shoulder of the post around the horn. At the Pecosmine round timber is used for all members of the set (fig. 3, C). A more elaborate framing of round

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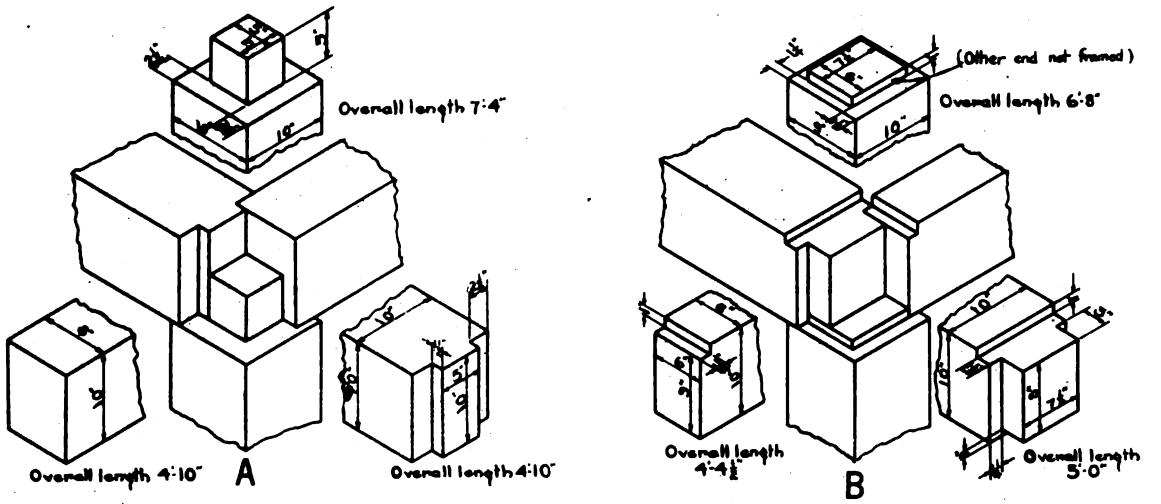

Figure 2.—Methods of framing joints: A, Cananea set, post-butting joint type; B, Bingham set, cap-butting joint type

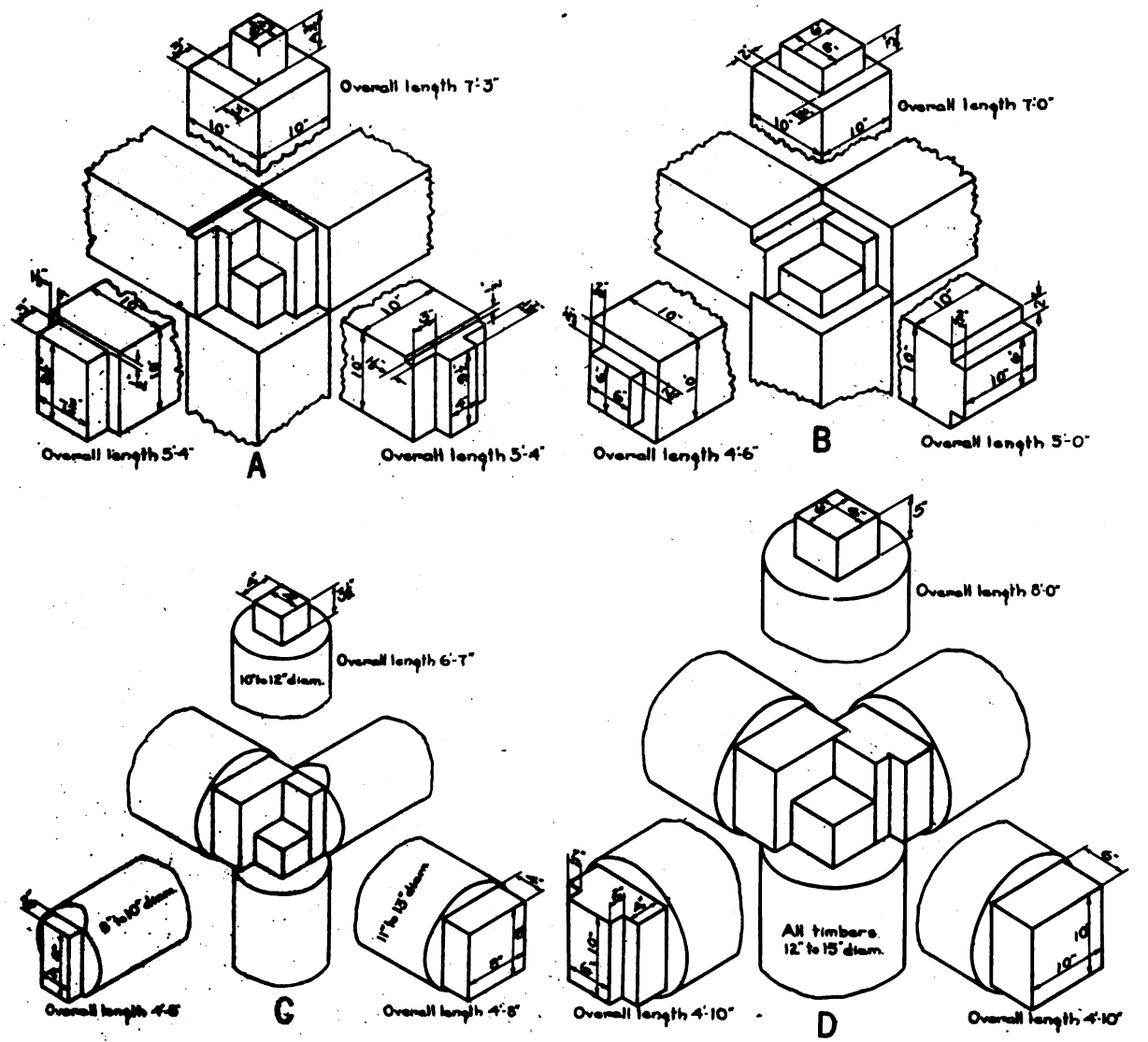

Figure 3.—Post-butting types of framing: A, Portland set; B, Burlingame set; C, Pecos mine set; D, Center Star set

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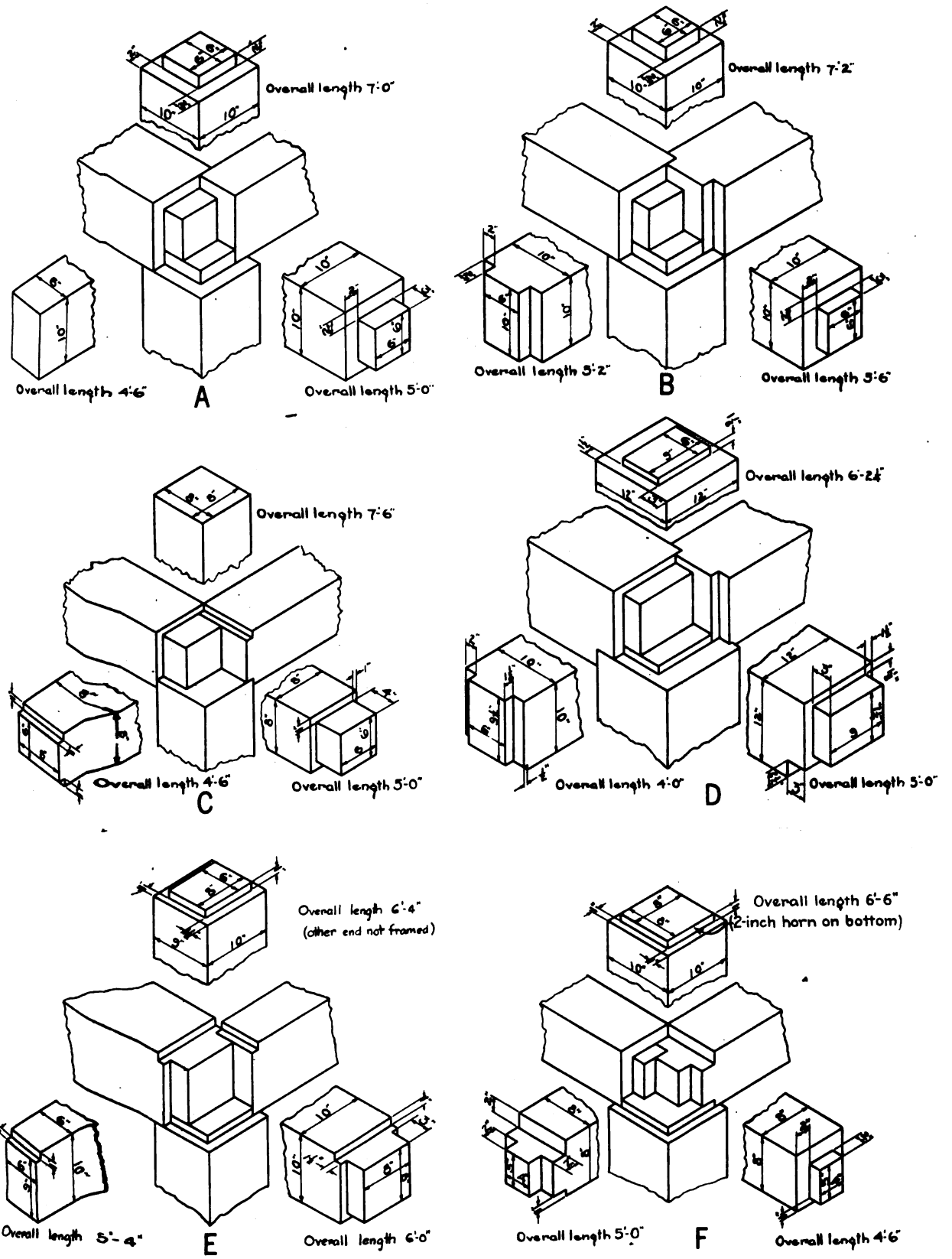

Figure 4.—Framing cap-butting sets with square timber: A, Butte set, 10-inch timber; B, Ruth mine set; C, Esperanza set; D, Richmond mine set; E, Tintic Standard set; F, New Idria set

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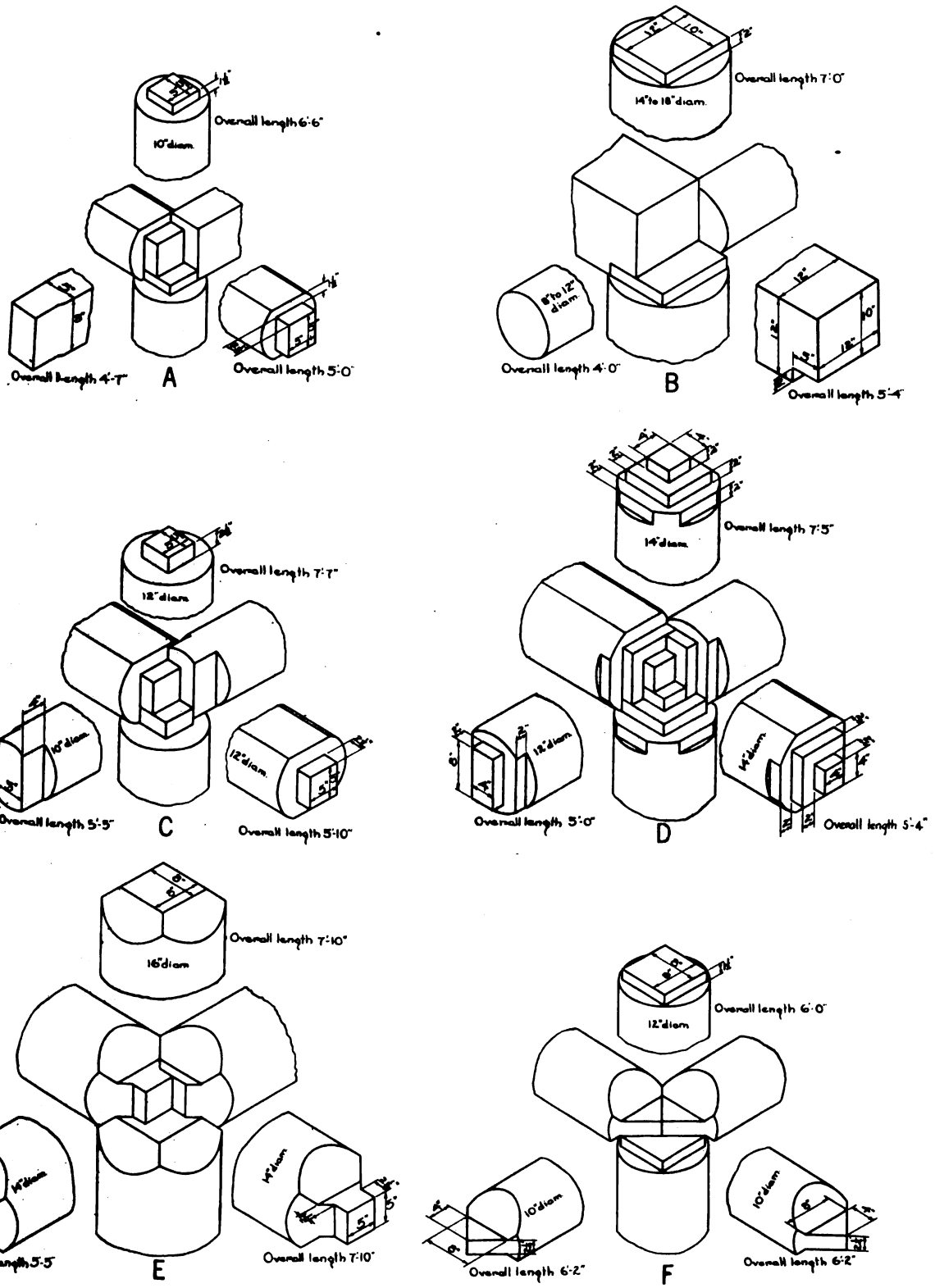

Figure 5.—Framing cap-butting sets: A, Page mine set; B, Argonaut mine set; C, Black Rock mine set; D, Anaconda step-down or Rocker set; E, Brunton bevel set; F, Chillagoe mine set

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timber is shown in Figure 3, D.

The principal variation in the method of framing cap-butting sets is in the manner in which the posts are cut. A post may be framed with a tenon on one or both ends; practice appears to be about evenly divided. At Butte a tenon is used on both ends of the post (fig. 4, A). The Bingham set (fig. 2, B), which is used largely in Utah mines, has a post with a tenon on the top only. The number of cuts taken by the saw in framing is the same in both cases; in the Butte set, however, the narrow girts are not framed, thus permitting a lower framing cost for the set. The types of framing shown in Figures 2, B, and 4, A, are those most commonly used; variations in the details of framing are mostly on account of the different-sized timber that may be used for the members of the set. Figure 4, B, shows a set in which all members of the set are of the same size, in which case the girts are framed. An unusual set is shown in Figure 4, C, in which the post is not framed. Only 24 cuts of the saw are required with this set.

In nearly all cases the bottom of the cap fits on a shoulder on the post. In Figure 4, C, the tenon on the cap fits flat on an unframed post. Figure 4, D, shows another unusual set in which the bottom line of the cap is dropped 2 1/2 inches below the shoulder on the post. In addition to increasing the amount of framing, it would appear that the ability of the cap to withstand downward pressure would be decreased.

The maximum resistance of a set to direct pressure applied normally in a straight line would be attained if the members of the set in this line butted together in full section. However, as the pressure is never all from the same direction or exactly in line with the sets, framing is necessary at the joints to prevent the sets from falling apart. The tenons on the posts hold the posts in place, should the sets be forced out of alignment; the length of the tenons should be as short as possible and still perform this function. A corresponding amount of cap must be cut away to allow space for a tenon on the post. At Butte, Mont. (fig. 4, A), at Ruth, Nev. (fig. 4, B), and at the Calumet and Arizona mine, Bisbee, Ariz., the tenons are 2 inches long with 10 and 12 inch timbers. In Utah (figs. 2, B, and 4, E) and in most of the Arizona districts a 1-inch tenon is used. At Jerome, Ariz., Leadville, Colo., and Tonopah, Nev., the tenon is 1 1/2 inches long. At the Copper Queen mine 5 by 5 inch tenons 2 1/2 inches long are framed on both ends of the posts. The post of the Eureka set (see Table 2) has a 2-inch tenon on the top and a 4-inch one at the bottom.

The shoulder around the tenon should be broad enough to prevent the girts from dropping out and to continue to provide a bearing for the bottom of the cap in case the alignment of the sets is lost. The width of the shoulder around the tenon is usually the same as the length of the tenon.

The cap of a set must, of course, be framed to conform to the tenon cut on the post. The girts usually require less framing than the other members of the sets. Figure 4, E, however, shows a set with elaborate framing and with tenons cut on all three members.

A set with a round post, a slabbed cap, and a squared girt is shown in Figure 5, A. A set with a round post, a round girt, and a squared cap is illustrated in Figure 5, B. A minimum of framing is done on this set. A tenon is framed only on one end of the post and a single right-angle cut taken out of the cap. A lagging or a small round girt placed between adjoining posts holds the bottom of the posts in place during blasting. Figure 5, C, shows a set with all round timber; the cap has been slabbed. Posts and caps in Figure 5, C, are framed alike and are interchangeable.

A step-down method of framing known as the "Rocker" (after the location of the framing plant) has been developed at Butte (fig. 5, D) in which round timber of various sizes is used. The joint is similar to the one used with squared timber (fig. 4, A), but the tenon on the post is of smaller cross section. The advantage of the Rocker framing is that it can be used with timber of any diameter and each step-down of a member rests on a similar step-

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down of another member, thus insuring a maximum rigidity of the set. Replacements are relatively easy. One side of the cap is slabbed to afford a flat bearing for a floor in the stopes. This elaborate type of joint would not be economical at mines where the sets were framed by hand. A similar joint is used at the Bawdwin mine (see Table 2).

A set with round timbers in which some of the bearing planes are beveled is shown in Figure 5, E. The Brunton square-set and bevel (Table 2) is similar, except that the tenons and horns are squared. Figure 5, F, shows a set designed to withstand equal pressure from both horizontal directions. The Unwarra V-framed set (Table 2) is similar, except that the squared horn on the post is 6 by 6 by 1 1/2 inches and the beveled tenons on the cap and girt are 5 inches thick. Joints having all bearing planes at right angles to each other are usually easier to install, especially where the sets already in are not in exact alignment.

A set which is useful in cases where a vertical post can not be placed is shown in Figure 6.

A stringer set of unframed timbers is illustrated in Figure 7, A. A spreader on the bottom of the cap holds the tops of the posts apart. A similar set, the Silver Hill, of 8-inch squared timber (see Table 2) is used at the Silver King mine in heavier ground. The ends of the caps framed with a 1 by 3 inch dap on the top and bottom. Both ends of the outside posts have a 1 by 1 inch dap, capwise. The end girts, 4 by 8 inches by 4 feet 8 inches long, are held in place by blocks nailed to the posts. Figure 7, B, shows a type of stringer set used in the Coeur d'Alene district. In this case the ends of the cap are blocked against the walls.

Table 2 gives the cubic feet of ore per set, board feet of timber per set, and board feet of lumber per cubic foot of ore with the various sets considered. The method of calculating the board-foot contents of round timbers is stated in Footnote 3 of the table. This was adopted as giving a figure better suited for the comparative purposes of this table than the method sometimes used of calculating the board-foot contents of the largest square timber which could be cut from the given round timber. In the latter case the formula would have been: Board feet = $0.041667\ d^2l$, and the resulting figures for board feet in cases of sets of all-round timbers would have been about 36 per cent lower than those shown. It will be noted that sets for which no illustrations are given are included in the table. The joints of these sets are framed in the general manner of the figure listed immediately above in each case.

DEVELOPMENT WORK

General Discussion

Usually the same general plan of development is used, whether the ore is to be mined by square-setting, or by open-stope, cut-and-fill, or shrinkage methods. The mine may be opened up by adits with or without interior shafts, or by shafts from the surface, depending upon the location of the ore deposits and the topography of the surface. Ore deposits which require the square-set method of mining are usually well below the surface, and shafts are required to reach them.

The preliminary work necessary for stoping, or stope preparation as it is sometimes called, depends, of course, upon the size of the orebody and the method of working. Such work includes extraction drifts, crosscuts, and raises, and the installation of chutes. The stope preparation necessary under various conditions is discussed later.

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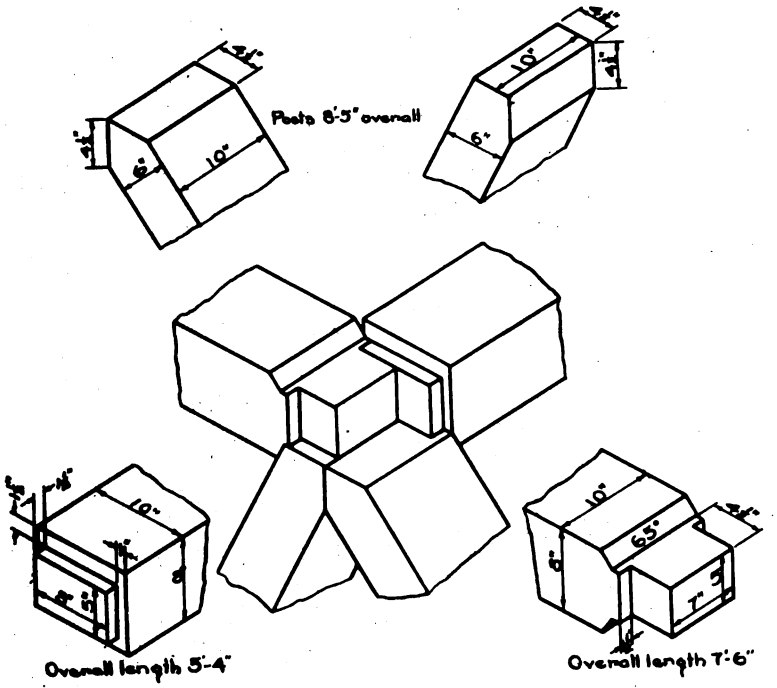

Figure 6.- Moore diagonal set

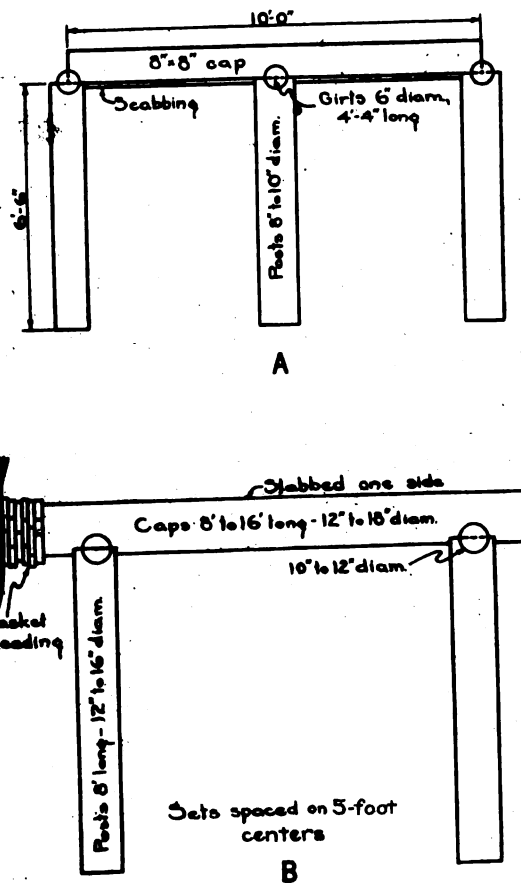

Figure 7.- Stringer sets: A, Silver King stringer set with unframed timbers; B, Morning mine set with ends of cap blocked against wall

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Shafts

Frequently the location and extent of an orebody is not known before the working shaft is sunk, and in such a case the shaft may not be placed in the most advantageous position. Whenever possible a permanent working shaft should be sunk in a rock formation that stands well and is free of faults. It should be at such a distance from the orebodies that it will not be disturbed by ground movement caused by subsequent mining operations, yet will be near enough so that unnecessarily long crosscuts need not be driven to reach the ore. Sufficient room should be available near the collar of the shaft for the necessary surface plant.

The size of the shaft should correspond to the duty required of it. Usually moderate daily tonnages are hoisted from mines using the square-set method of mining. At such places the shafts usually contain 3 or 4 compartments. The present tendency in mining is to hoist ore in skips; however, at mines producing two or more classes of ore and requiring all current development waste for filling, hoisting or lowering in cages may be more satisfactory.

Level Interval

The best interval to use at any mine is dependent mainly upon the geologic conditions existing at the mine. As the level interval is increased, a saving is made in that fewer levels are required. The cost of haulage and development drifts, shaft stations and loading pockets, and chutes under stopes must be course be charged against the ore mined. The saving in having fewer levels must, however, be balanced against the greater cost per foot of driving long raises, and the higher cost of maintaining long raises in heavy ground and long ore chutes when the ore is abrasive. Where unusually long crosscuts are necessary a relatively longer interval would be used; in such cases sublevels may be driven. Where the orebodies are irregular in size and form, levels or sublevels must be relatively close together to prospect the ground and develop the ore properly. Moreover, in such cases short intervals are desirable to obviate the necessity of driving raises through waste to reach the ore.

The wall rock or ore, or both, usually are weak where the square-set method of mining is used. In large, irregular orebodies and in wide veins, weight is likely to develop on the level below or in the stopes before a block of ground is mined out. In such cases a short level interval is desirable in order that a stope may be completed as quickly as possible and that long raises need not be maintained ir heavy ground.

Where the orebodies are regular, relatively long intervals may be desirable in some cases, even if excessive repair work is required in maintaining ore passes and raises.

In the early days of mining, levels were usually run on 100-foot intervals. It has been found in many places, however, that longer intervals are more economical. This interval at different mines has been increased to 150, 200, 250, and finally to 300 feet. In most places, however, it has been found that these last two distances are not practical. Where the interval is 250 or 300 feet, sublevels midway between the main levels generally are used for bringing waste and supplies into the stopes and for starting points of development raises. Sublevels are also used at other places in extremely heavy ground. Level intervals at 19 mines using the square-set method of mining are shown in Table 3.

Drifts and Crosscuts

Drifts are driven either in the vein or parallel to the vein. Drifts parallel to the vein usually are run in the footwall. In wide orebodies drifts in the vein may be run both on the hanging wall and footwall. Where the ground is heavy and the drift timbering in a vein has to be replaced a number of times before the ore is mined, driving the drifts in the

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firmer wall rock is more economical. The expense of maintaining the drifts in heavy ground may be more than the cost of driving the laterals in the solid rock. Haulage drifts should be double-tracked near the shaft, and passing tracks should be provided at other convenient places. A standard drift set is shown in Figure 8, A. A drift set used at turnouts and switches is shown in Figure 8, C. The methods of timbering different types of drifts at the Magma mine are shown in Figure 8, B, D, and E.

Usually levels are allowed to stand as long as practicable before beginning stoping, in order to let the ore dry out as much as possible. Sof ground on becoming wet may run readily, and it is best handled by draining the water from the workings and allowing the level to dry out before attempting to remove the ore. When thoroughly drained, veins containing ore of this character are often worked without great difficulty. Mining such ground without first draining may be very expensive.

Raises

In large stopes timbered with square-sets at least one raise should be driven to the level above before starting stoping operations. This improves ventilation, prospects the ground, supplies an additional exit for the workmen, and provides a means of getting waste fill into the stopes; such raises are also used for lowering the timber into the stopes, thus avoiding the more expensive method of hoisting it.

In most cases standard stope sets are used for raise timbers. The raises are offset to follow the dip of the deposit. The use of standard sets in raises permits making connections with the stope timbers with little difficulty as stoping advances. Two and three compartment raises are classed as 6-post and 8-post raises, respectively. The 2-compartment raises consist of a manway and a chute; the 3-compartment raises contain two chutes and one manway, or one manway, one chute, and one timber slide. In the 3-compartment raises with two chutes the manway is usually in the center and the raise is made to serve two sections or stopes.

Figure 9 shows a standard 6-post manway used at the United Verde Extension mine.[11] The chute compartment is lined with 2 or 3 inch Douglas fir, depending upon the service expected. The manway contains a timber slide in one corner and has landing platforms on each floor.

At the Pecos mine raises driven for bringing filling into stopes are about 4 by 6 feet in section. Three-inch plank is nailed to one side of a row of stulls along the center line of the raise to form a manway. In some places these raises must be cribbed, in which case they are larger, with two 4 by 4 foot compartments.

At the Ground Hog mine the raises are 4 by 7 feet in section and are stulled. They are nlarged and lined with square-sets ahead of stoping. Chutes are not generally used in raising at this mine, the broken material falling onto a platform at the foot of the raise, from where it is shoveled by hand into cars. This is done to avoid the accumulation of gas from blasting, which is held back in a raise closed by a chute.

Cribbed raises (see fig. 10)[12] are sometimes desirable for ventilation purposes in heavy ground. They are not used as working raises in a square-set stope unless absolutely necessary, due to the difficulty of tapping them for drawing waste for filling and of standing the adjacent stope timbers.

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[11] – D'Arcy, Richard L., Mining Practice and Methods at the United Verde Extension Mining Co., Jerome, Ariz.: Information Circular 6250, Bureau of Mines, Feb., 1930, 11 pp.

[12] – Snow, Fred W., Mining Methods and Costs at the Magma Mine, Superior, Ariz.: Inf. Circ. 6168, Bureau of Mines, Sept., 1929, 32 pp.

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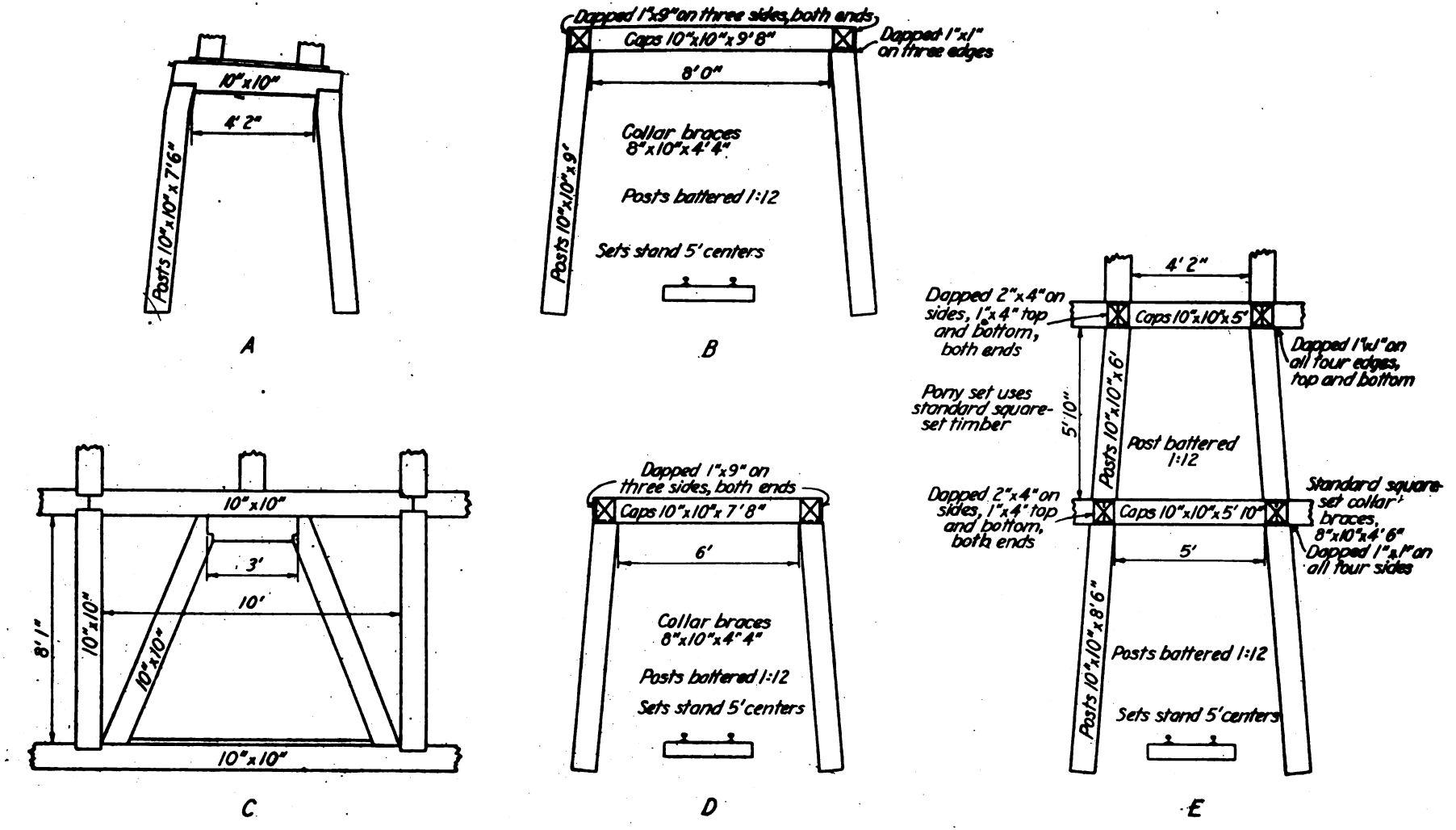

Figure 8.- Methods of timbering drifts: A, Standard drift set; B, timbering for main ventilation and haulage drifts, Magma mine; C, turnout set; D, footwall-drift timbering, Magma mine; E, extraction-drift timbering, Magma mine

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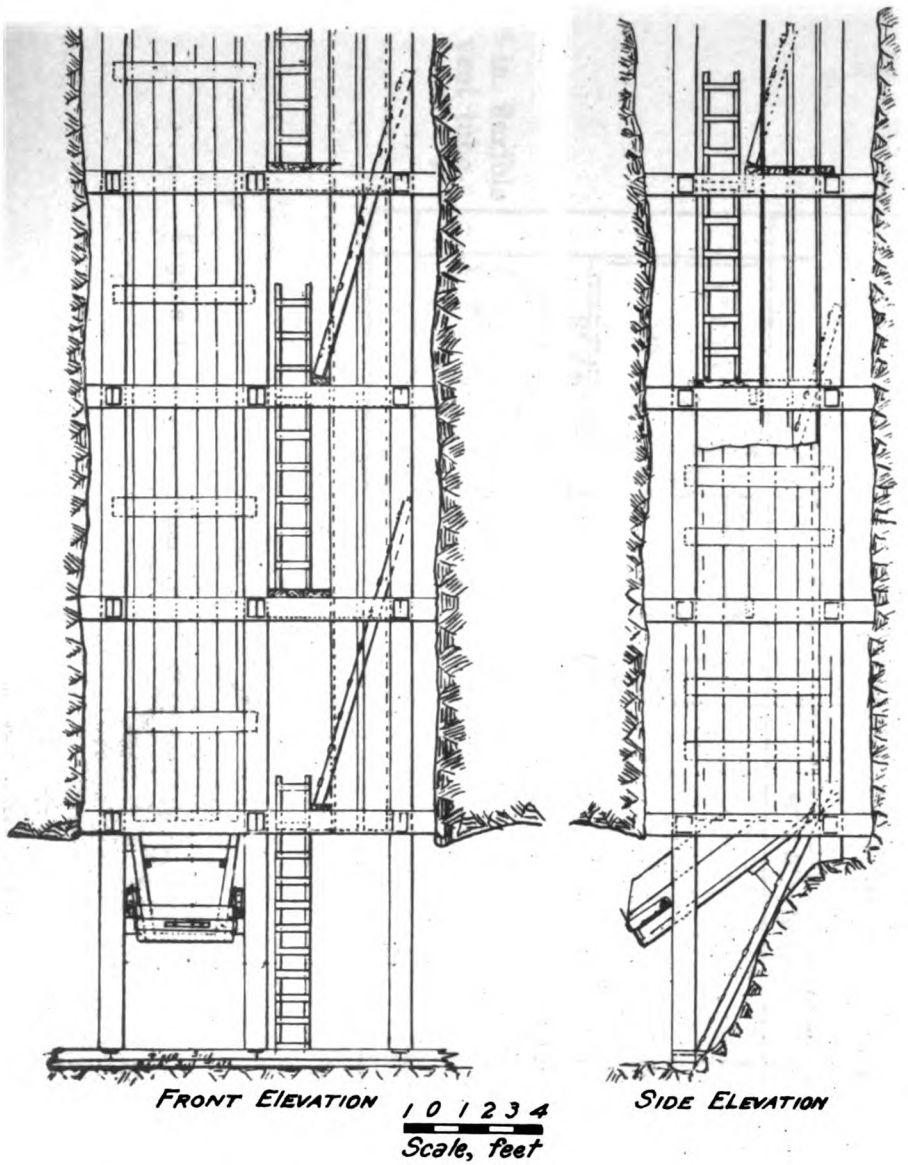

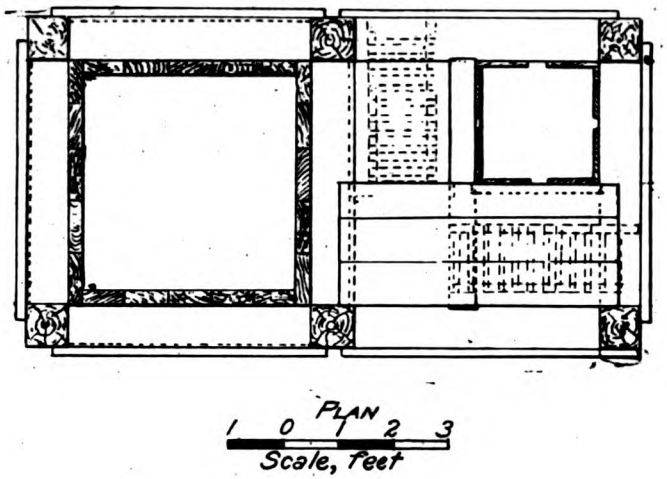

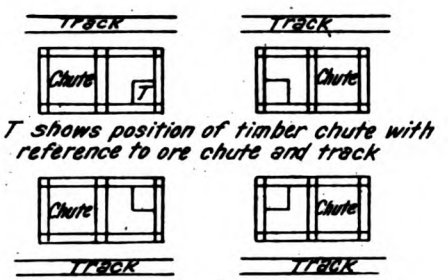

Figure 9.- Standard 6-post square-set raise with safety manway, United Verde Extension mine

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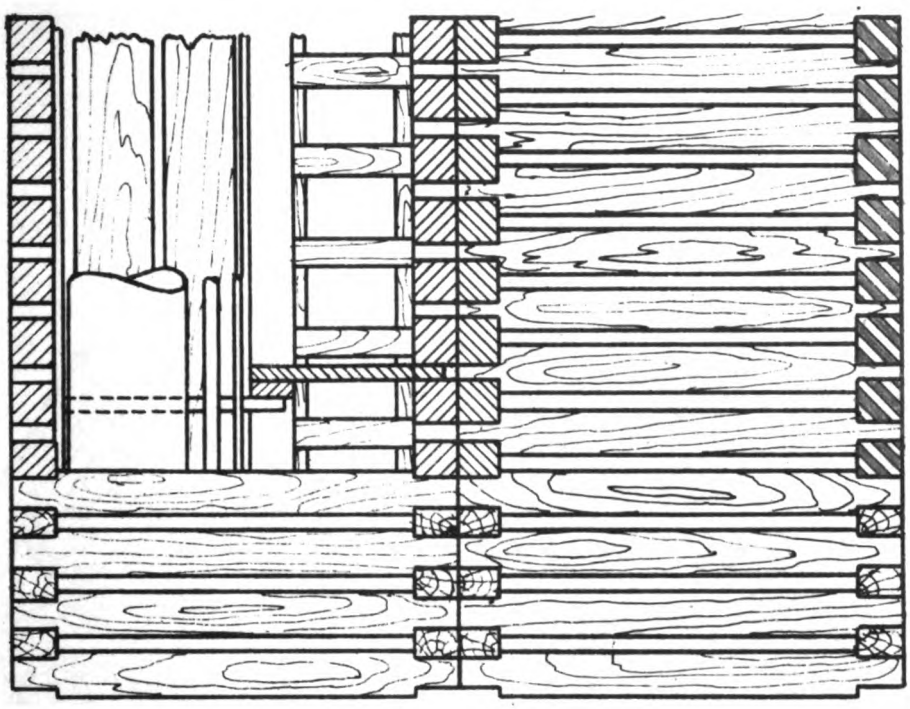
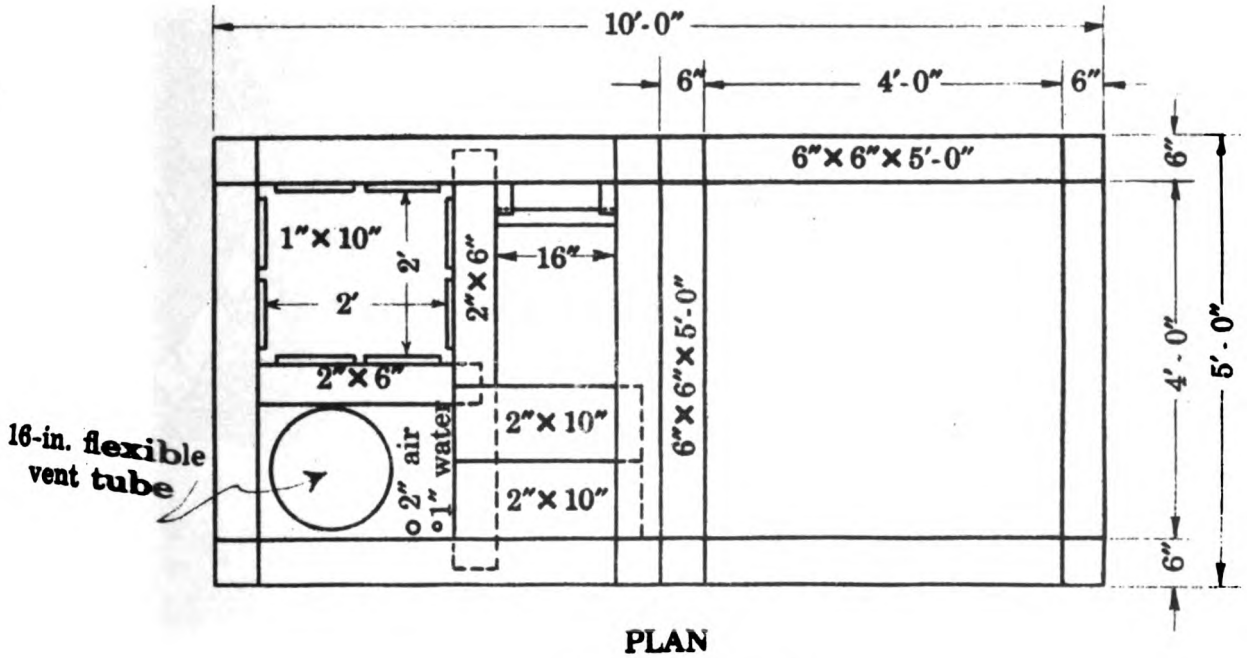


ELEVATION AND SECTION



PLAN

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Figure 10.- Two-compartment cribbed raise, Magma mine

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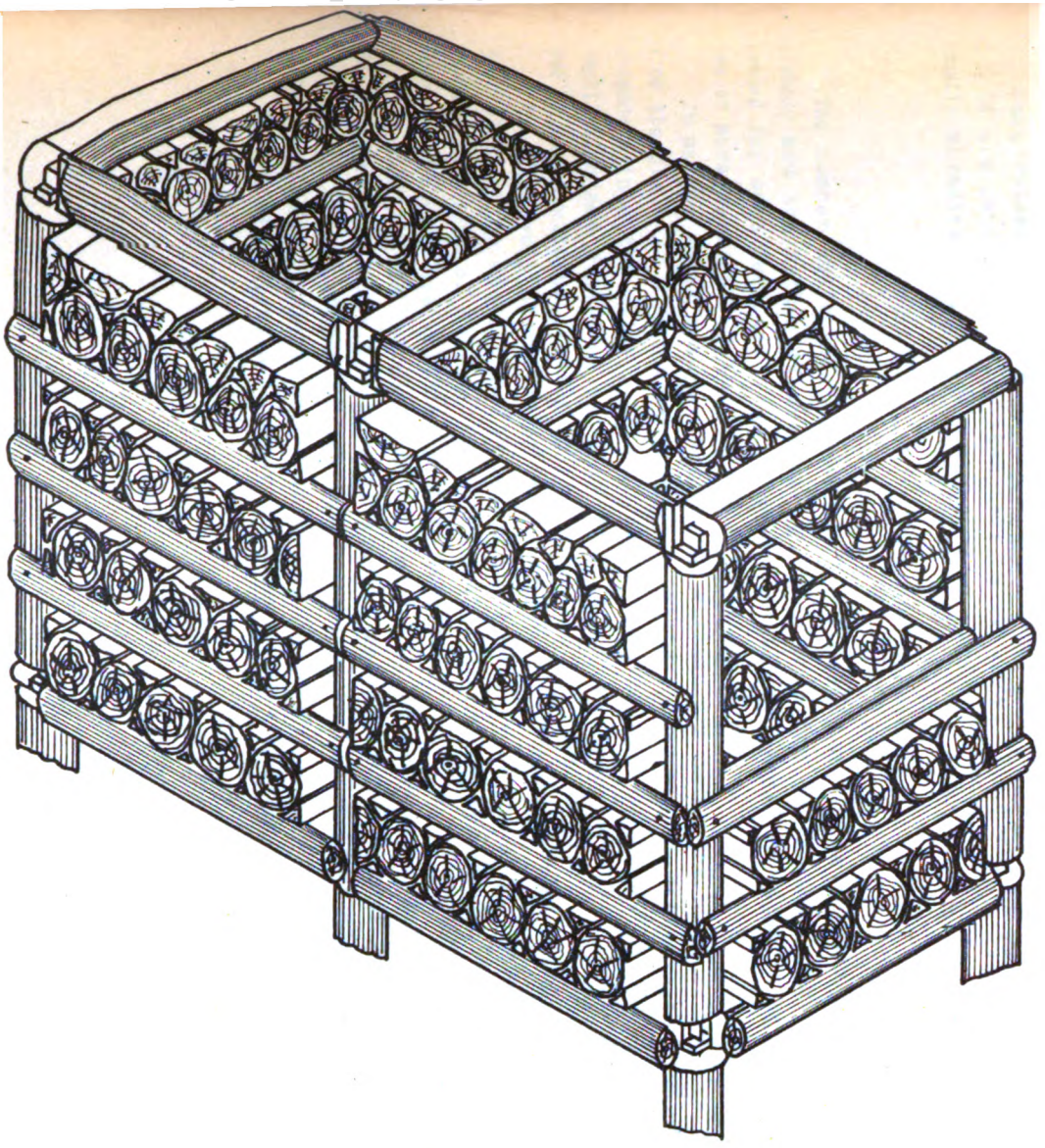

Figure 11.- Method of lining a chute and manway with bricking, Black Rock mine

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In heavy ground chutes may be timbered by a process known as "bricking" (see fig. 11).[13] In this method blocks of round timber 20 inches long are placed between the sets, the layers of blocks alternating with round timbers spiked between the posts. The wear is confined largely to the ends of the blocks. A "bricked" chute will stay open longer and stand more wear from rock than a planked chute, and in heavy ground it will tend to steady a stope, as does a bulkhead.

Long raises should be offset occasionally to break the fall of the ore. Raises kept full of ore last longer than when this is not done. Ore mined by square-set methods is not usually abrasive, which lowers the cost of upkeep of chutes.

Spacing of Raises

The number and spacing of raises for a square-set stope depends upon the size of the orebody and the method of working it. Where the ore is taken out in sections a raise is needed for each section. Such a raise is usually placed adjacent to or at the corners of two or more sections so that it may serve all of them.

In narrow veins enough material for filling may sometimes be obtained by sorting waste from the ore. In other cases any added waste needed may be obtained by running raises or crosscuts into the walls. In such cases the only need of raises to the level above is for ventilation and providing an extra exit from the stope. In flat, tabular deposits the ore may be mined without putting up any raises to the level above.

In relatively narrow veins raises are put up from 50 to 140 feet apart. The expense of transporting the waste from the raises to the middle of the stope between raises is balanced against the cost of driving them. Generally in narrow stopes the raises are far apart; in wide stopes they are relatively close together.

In a wide vein the distance between waste raises depends upon the length of the stope, distance between levels, speed of stoping operations, character of the ore and enclosing rocks, dip and thickness of the vein, distribution of waste in the vein, control of water, and convenience in the circulation of air currents.

The raise intervals at representative mines are given in Table 3.

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[13] - McGilvra, D. B., and Healy, A. J., Methods of Mining at the Black Rock Mine, Butte & Superior Mining Co., Butte District, Mont.: Inf. Circ. 6370, Bureau of Mines, Dec., 1930, 16 pp.

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Table 3.- Stoping data at representative mines using square-set methods of mining

(Section A)

Mine	Level interval, vertical distance, feet	Spacing of chutes under stopes, feet	Space between level-to-level raises, feet	Position of sill floor	Size of sills, inches	Size and type of sets	Methods of advance of sections
Anaconda	100 and 200	25-40, narrow veins; 25-30, wide veins	25-75, wide veins; 90-120, narrow veins; 50-150, rill	Usually above drift	Not used	See Figure 5, D	Horizontal and rill
Argonaut	100 and 150	25	100	Above drift sets or bridging	12 by 12	See Figure 5, B	Horizontal
Page	230	35	140	Above bridging	12 by 12	See Figure 5, A	Horizontal
Pecos	100	15 and 30	30-60, narrow veins; 100-150, wide veins	12 feet above back of drift sets	-	See Figure 4, C	Horizontal
Central Eureka	100 to 150	25	-	Above bridging	Not used	-	Horizontal
Black Rock	100 and 150	30	20 to 60	Top of drift sets	Not used	See Figure 5, C	Horizontal
Hecla	200	100	200	At drift level	-	See Figure 7, D	Horizontal
Morning	200	125	125	Above drift sets	14 to 18, round timbers	See Figure 7, B	Horizontal
Silver King Coalition	100	Variable	Variable	At drift level	-	See Figure 7, A	Horizontal

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Table 3.- Stoping data at representative mines using square-set methods of mining - Continued

(Section A - Continued)

Mine	Number of floors open at a time	Horizontal area of section	Method of handling ore in stopes	Sorting or waste from ore in stopes	Kind of rounds drilled in stopes	Method of placing filling	Source of waste for filling
Anaconda	2	-	Shoveling, slides	About 25 per cent	Vertical and inclined	Gravity and cars	Crosscuts in walls, sorting, development
Argonaut	1	Width of vein by 20 sets long	Slides, shoveling	None	Horizontal	Gravity and shoveling	Chambers or crosscuts in walls
Page	2 or 3	Width of ore, up to 250 feet long	Wheelbarrows, gravity	Some	Horizontal	Scrapers	Sorting, crosscuts in walls
Pecos	2	3 sets wide by width of vein	Shoveling	Some	Horizontal and vertical	Gravity and shoveling	Sorting, surface, development
Central Eureka	2	Width of vein by 15 sets long	Gravity, shoveling	None	Horizontal	Gravity and shoveling	Chambers in walls
Black Rock	2	2 sets wide by 4 to 10 long	Slides, shoveling	Selective mining	Horizontal and vertical	Gravity and shoveling	Sorting, old fills, development
Hecla	2	Width of vein by up to 100 feet long	Cars	-	Vertical	Cars	Development, surface
Morning	3 or 4	Width of vein by up to 250 feet long	Cars	Some	Horizontal	Scrapers	Sorting, crosscuts in walls
Silver King Coalition	-	-	Wheelbarrows, cars	15 to 20 per cent	Horizontal and vertical	Wheelbarrows, gravity, and shoveling	Sorting, development

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Table 3.- Stoping data at representative mines using square-set methods of mining - Continued
(Section B)

Mine	Level interval, vertical distance, feet	Spacing of chutes under stopes, feet	Space between level-to-level raises, feet	Position of sill floor	Size of sills, inches	Size and type of sets	Methods of advance of sections
Ground Hog	100 (sublevels at 50 feet for development purposes)	50	50	At drift level	10 by 10	-	Rill
Magma	125 and 150 (haulage drifts 250 and 300 feet apart)	15 to 25	One to a section or stope	At drift level	-	-	Rill
Park Utah	150	50	100	Top of drift sets	6 by 10	-	Rill
Cananea (Colorada mine)	125	30	30	11 feet above drift level	Not used	See Figure 2, A	Vertical
Bunker Hill and Sullivan	200	15 to 20	About 200	At drift level	6 by 10	-	Vertical
Old Dominion	100	30	Multiples of 30	-	-	-	Vertical
Tintic Standard	120	-	-	At drift level	6 by 10	See Figure 4, E	Vertical
United Verde Extension	100	22	33 (along each section)	Above drift sets	10 by 10	-	Vertical
Copper Queen	100	20 to 50	20 to 50	-	10 by 10	-	Vertical and horizontal
United Verde	150	-	-	Top of drift	10 by 10	-	Horizontal and rill (pillars)

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Table 3.- Stoping data at representative mines using square-set methods of mining - Continued

(Sectio B - Continued)

Mine	Number of floors open at a time	Horizontal area of section	Method of hardling ore in stopes	Sorting of waste from ore in stopes	Kind of rounds drilled in stopes	Method of placing filling	Source of waste for filling
Ground Hog	-	-	Shoveling, gravity	Some	Inclined	Gravity	Development, sorting
Magma	3 (before filling)	Width of vein by up to 40 feet long before filling	Gravity	None	Vertical	Gravity	Surface glory hole, development
Park Utah	6	Width of vein by 10 sets long (first section 20 sets long)	Scrapers	None	Horizontal	Gravity	Development
Cananea (Colorada mine)	2	3 sets wide by width of vein	Wheelbarrows, shoveling	None	Horizontal	Scrapers, wheelbarrows, and shoveling	Surface glory holes, development
Bunker Hill and Sullivan	6 to 10	1 to 4 sets wide by up to 33 sets long	Gravity, shoveling	None	Vertical and inclined	Cars and gravity	Development
Old Dominion	2	3 sets wide by width of vein	Wheelbarrows, slides, shoveling	Occasional sorting of oxidized ore	-	Gravity, wheelbarrows, shoveling	Development, waste raises
Tintic Standard	Up to 8	2 sets wide by up to 20 long	Gravity, shoveling	Selective mining	Horizontal and vertical	Gravity and shoveling	Surface and development
United Verde Extension	2	1 to 3 sets wide by 10 to 20 long	Shoveling, slides	None	-	Gravity, cars or wheelbarrows	Development
Copper Queen	-	-	Gravity, some shoveling	-	Horizontal	Gravity	Development, old fills
United Verde	1 (horizontal) 2 (rill)	3 sets by 7 sets (horizontal); 2 sets by 10 sets (rill)	Shoveling, wheelbarrows	-	Horizontal	Gravity and cars	Surface stripping, development

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STOPING PRACTICES WITH SQUARE-SET MINING

Stoping practices are nearly uniform in square-set mines. Drilling practices vary mainly in accordance with the types of drills used. Blasting in similar ground is nearly uniform, and the manner of standing and blocking sets varies but little at different mines. The methods of silling out for stopes, removing the ore, and putting in filling differ in accordance with the variations in the stoping methods.

Drilling and Blasting

As usually only enough ground is broken at a time to stand a set, and relatively few holes are needed, the drilling of rounds is not a major operation when mining in square-set stopes. Horizontal holes have an advantage in that the breaking of the ground can be better controlled than with vertical holes. A further advantage exists in that the back is shattered less in blasting. Consideration must be given to the predominating planes of weakness in the ore to avoid excessive overbreak. Where the planes are flat a vertical round will cause a minimum overbreak, and with vertical planes horizontal rounds will give the best results in this respect.

Stoper drills are used in the majority of square-set mines. At some mines, however, breast stoping with light mounted drills is preferred, and hand-held jackhammers are frequently used in soft ore. What is in effect a horizontal round can be drilled with stopers by holding them in an inclined position. Vertical rounds with stopers have an advantage in that the back over a number of sets may be drilled at one time before any blasting is done; where horizontal holes are used one round must be blasted before the next can be drilled. The stoper has a further advantage in that a column is not necessary, which saves the time of setting up and allows more flexibility in the pointing of holes; this advantage, however, may be lost if stagings must be erected for the men to stand on in order to drill. Although wet stoper drills have been used successfully for many years at a number of mines, difficulty is encountered at other places in keeping the men from using the machines dry; drilling without water creates a health hazard from dust. At some mines it has been found that drill repair and breakage of steel is less with light mounted machines than with stopers.

At Butte, stopers are used in all stopes.[14] Figure 12, A, shows a round drilled from the floor below for starting a floor next to a chute. Such rounds generally are blasted lightly to prevent injury to the chute. Figure 12, B, shows the starting of a floor at a raise by drilling from the same level. The ore generally is shattered and slabby in the vicinity of a raise. The chute lining is ripped out on one side to allow an entrance to the ore against the raise.

The method of starting the first floor from the drift level is shown in Figure 12, C. If there is no interference with traffic, a staging is built and a deep round is drilled and blasted down on a floor laid on the sill.

In stopes where raises have not been run the first round in any floor must, of course, be drilled from below; subsequent rounds may or may not be drilled in the same way. Where the ground is riding on the timber on top of the sets the top lagging is cut before the round is blasted to relieve the strain on the timber. The manner in which a round is drilled at any particular place is usually dictated by the miner's judgment. Rounds drilled from below at a raise are more likely to break the raise timber than when the other method is used.

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[14] - Harrer, Clarence M., Square-Setting in the Butte District: Eng. and Min. Jour. Vol. 124, July 30, 1927, p. 167

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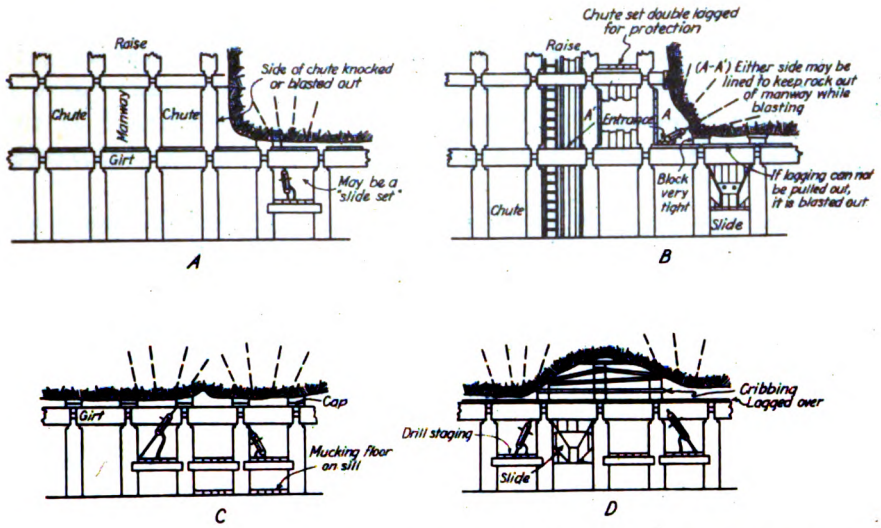

Figure 12.- Drilling with stopers, Butte district: A, Starting a floor at a raise by drilling from below; B, starting a floor at a raise by drilling at the same level; C, drilling first floor from drift; D, method of drilling overhead in loose ground

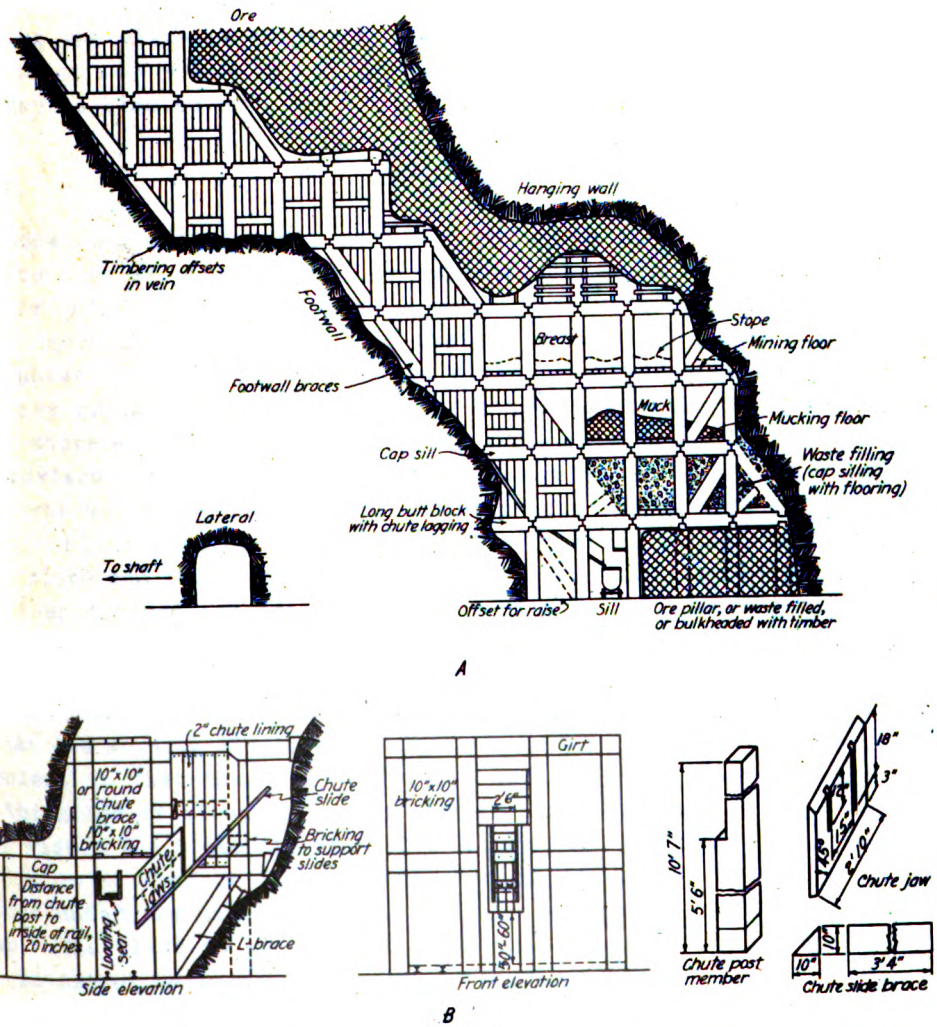

Figure 13.- Stope timbering details at Anaconda mine, Butte: A, Transverse section of stope in a wide flat vein; B, chute construction details

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Blasting in any square-set mine must be done with care and the holes must not be overloaded, in order that the timbers may not be broken. Also, for the same reason, judgment must be used in placing the holes. The back of the stope should be jarred or shattered as little as possible. As low a grade of explosive as will break the rock satisfactorily should be used.

Care is needed in drilling vertical holes so that the drillers are protected from falling ore. Two strips of lagging usually are placed overhead and shifted about to afford protection, should a fall of rock occur. Before blasting a round, the manway generally is covered with two thicknesses of lagging and flooring laid on the shoveling floor. Where two floors are kept open the regular flooring immediately below the blast may be protected by laying old lagging on it, or a grizzly of double lagging may be spiked to the caps to break the fall of the ore. If slides are to be used to get the broken ore into the chute, they usually are built before the round is blasted.

After a blast the floor is cleaned and broken timbers replaced. The space where the next set is to be placed is then barred down. Occasionally the regular blast will not break high enough to place a set, in which case "plugs" may be drilled and shot during the lunch hour. Blasting during the shift, however, is not considered good practice unless the ventilation is good.

A method of drilling loose ground is shown in Figure 12, D. All the sets except the one in which the slide is built are lagged over before blasting to hold the round. In some cases the slide may be put in and in others the cribbing removed first. In still others the cribbing may be blasted out.

Removing Broken Ore

In stopes where horizontal sections are mined the ore may be shoveled directly into chutes, into cars or wheelbarrows, or run into the chute by slides built in sets below the mining floor. The practice followed depends upon the distance apart of the ore chutes, the number of floors open at a time, and whether or not the ore must be sorted. In vertical sections, unless the ore must be sorted it is usually run into chutes by means of slides. In very heavy ground where only one floor can be kept open at a time, most of the ore may have to be shoveled. The methods of using slides are shown later.

The maximum distance that ore can be shoveled without rehandling is about 15 feet; therefore, where the ore is shoveled directly into chutes they should not be over 25 or 30 feet apart. Floor lagging is usually laid with the line of shoveling. Where long, flat slices are mined and two floors are kept open, the ore may be caught on lagging on the upper floor and then dropped into cars on the floor below. Where three floors are kept open the ore is usually caught on the middle or shoveling floor and loaded into cars on the floor below. The ore may be dropped or shoveled through holes made by taking up the lagging one at a time or by removing short pieces of boards placed crosswise over a space left between lagging. At the Morning mine the ore is shoveled through movable steel slides. These slides are convenient in that they can be quickly moved from one set of timbers to the next. In this way the slide is always close to the pile of broken ore. The slide is 5 1/2 feet long and 2 feet wide. The sides are made of a triangular piece of steel 3 feet wide at the bottom and tapering to a point at the top. The top of the slide rests upon a cap. The lower end is suspended under the next cap and is held in position by chains hooked over spikes driven in the cap. The slide is so designed that when in this position the lower end just clears the car. It is not necessary to use side boards on the car when loading from the slide.

Ore chutes usually are covered by grizzlies to prevent men from falling into them and to keep out rocks too large to be readily handled below. Usually the character of the ore broken in a square-set stope is such that very little secondary breaking is necessary.

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Ore Chutes

The distance between ore chutes depends upon the method of mining. In narrow veins or sections one line of chutes is sufficient. In wide sections more than one line may be used. Where the ore is mined in long horizontal slices chutes may be maintained at intervals through the fill or only at the ends of the block. The cost of building and maintaining the chutes must be balanced against the expense of hand tramming in the stopes. Another factor also must be considered—the sets in which the chutes are built can not be filled. In some cases this open space may weaken the stopes sufficiently to add to the expense of mining.

As shown in Table 3, the ore chutes at representative mines are from 15 to 125 feet apart.

At most mines the ore chutes are carried up as stoping progresses and consist of a vertical line of square-sets lined on the inside with lagging. The square-sets are offset whenever needed to keep within the vein. At intervals a manway is maintained alongside a chute in another series of square-sets.

Figure 13, A, shows the type of ore chute used at Butte. The car loaders sit in a perch nailed between two sets. The flow of ore is partly controlled by their feet. The details of the chute mouth are given in Figure 13, B.

Chute gates have been described in considerable detail by Jackson and Knaebel.[15]

Placing Square-sets

Mention has been made of the care that should be taken in framing the joints of square-sets. The effect of such care is lost if the timbers are not properly placed in the mine. The posts should be plumb and at right angles to the caps and girts. The outside corners of the sets should be blocked tightly to the walls or back of the stope. To obtain the full strength of a set the members are put under compressive strain as the set takes weight. For example, when the tops of the sets are blocked immediately over the posts and the pressure is downward, the caps and girts impart strength to the assembly by holding the posts rigid. Should the set be blocked from above in the middle of the cap, downward pressure would break the cap long before the full strength of the set was utilized.

In placing square-sets the most important factor is blocking and wedging. Wedges should be properly and firmly driven and they should receive attention from time to time to see that they do not become loosened by ground movement or by blasting. The principle of square-set timbering is to render the entire structure of timber as rigid as possible so as not to permit any subsidence or lateral ground movement; as a general rule when the ground once starts to move it is difficult and expensive to hold it.

When sets are lagged against rock in place they should be watched; whenever excessive weight is indicated by the lagging's bending inward, a few pieces of lagging should be cut out and the pressure relieved by removing some of the rock.

In heavy ground each round should break just enough ore to stand one set and the sets should be stood and securely blocked as soon as practicable. Where the sets can not be blocked to the face for several shifts, they are likely to be swung out of alignment. Pressure should be relieved whenever practicable before alignment of the sets is lost, as their ability to resist strain is greatly reduced when they are forced out of the right-angle position they should occupy. Sets may also be forced out of line by the settling of the fill or the breaking of timbers in either the filled or unfilled part of the stope.

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[15] - Jackson, Chas. F., and Knaebel, John B., Underground Chute Gates in Metal Mines: Inf. Circ. 6495, Bureau of Mines, August, 1931, 22 pp.

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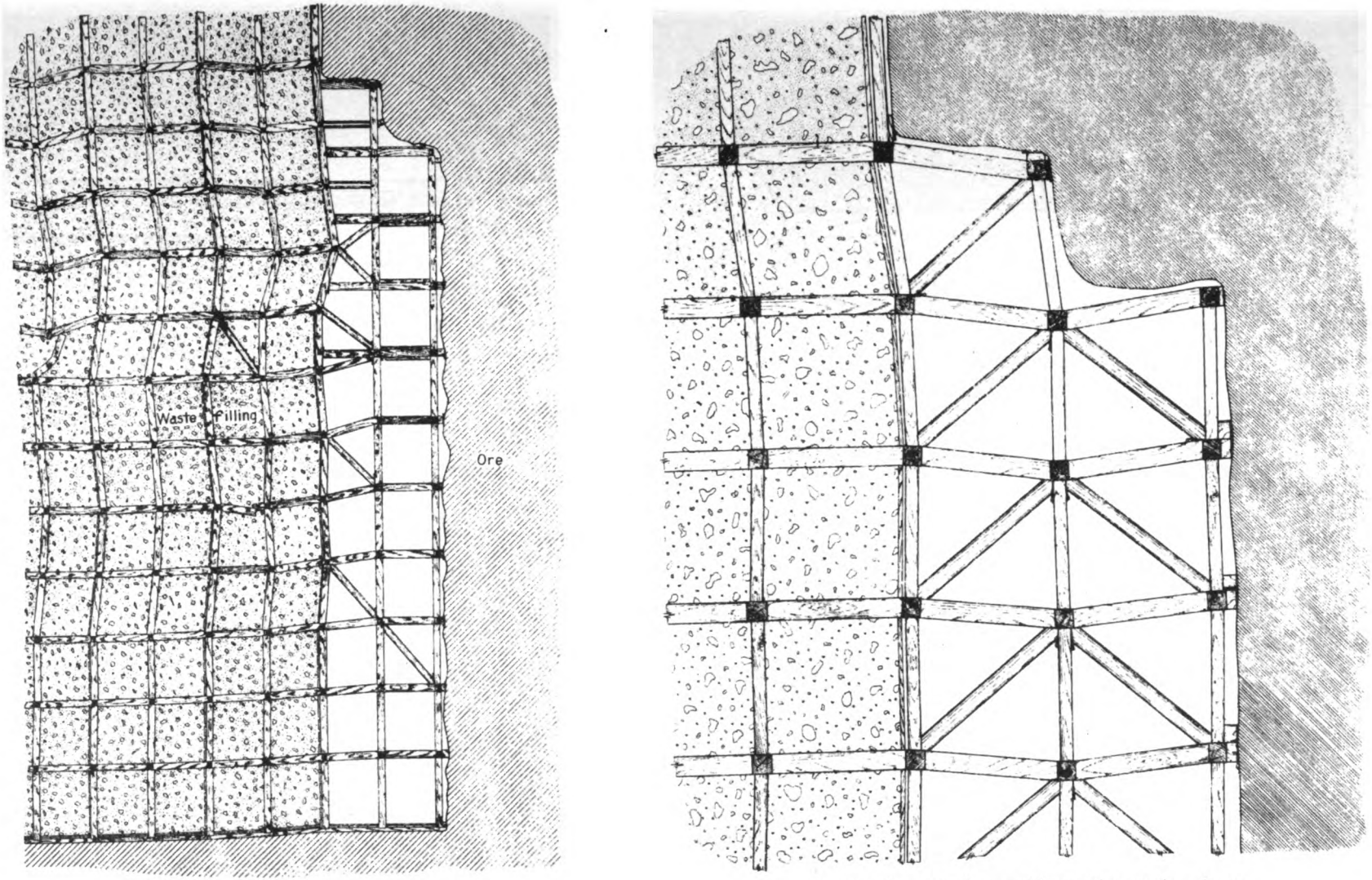

A. Vertical section through stope

B. Horizontal section through stope

Figure 14.- Method of timbering in heavy ground at the Tintic Standard mine

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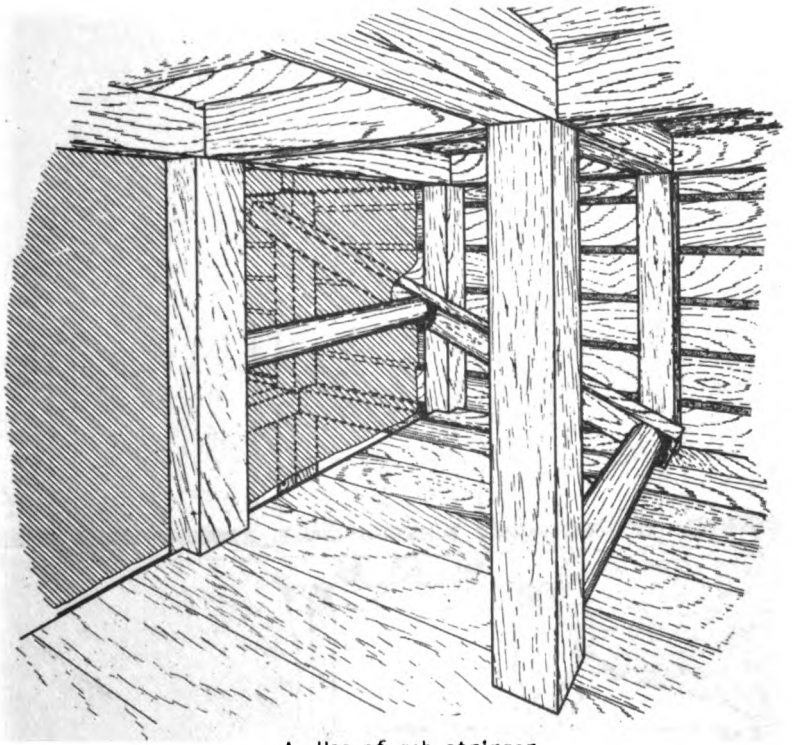
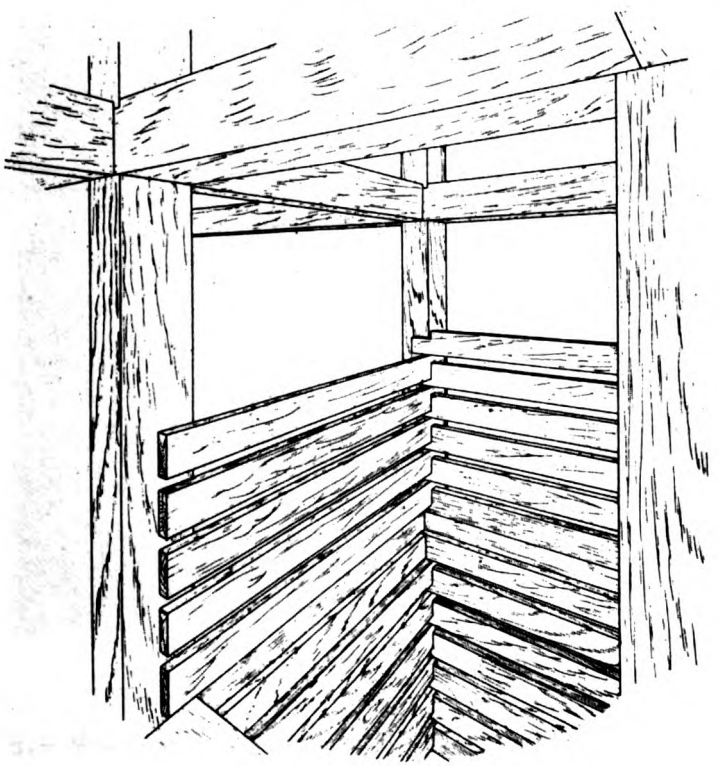


A. Use of gob stringer



B. Method of placing corner lacing

Figure 15.- Methods of reinforcing timbering at the Tintic Standard mine

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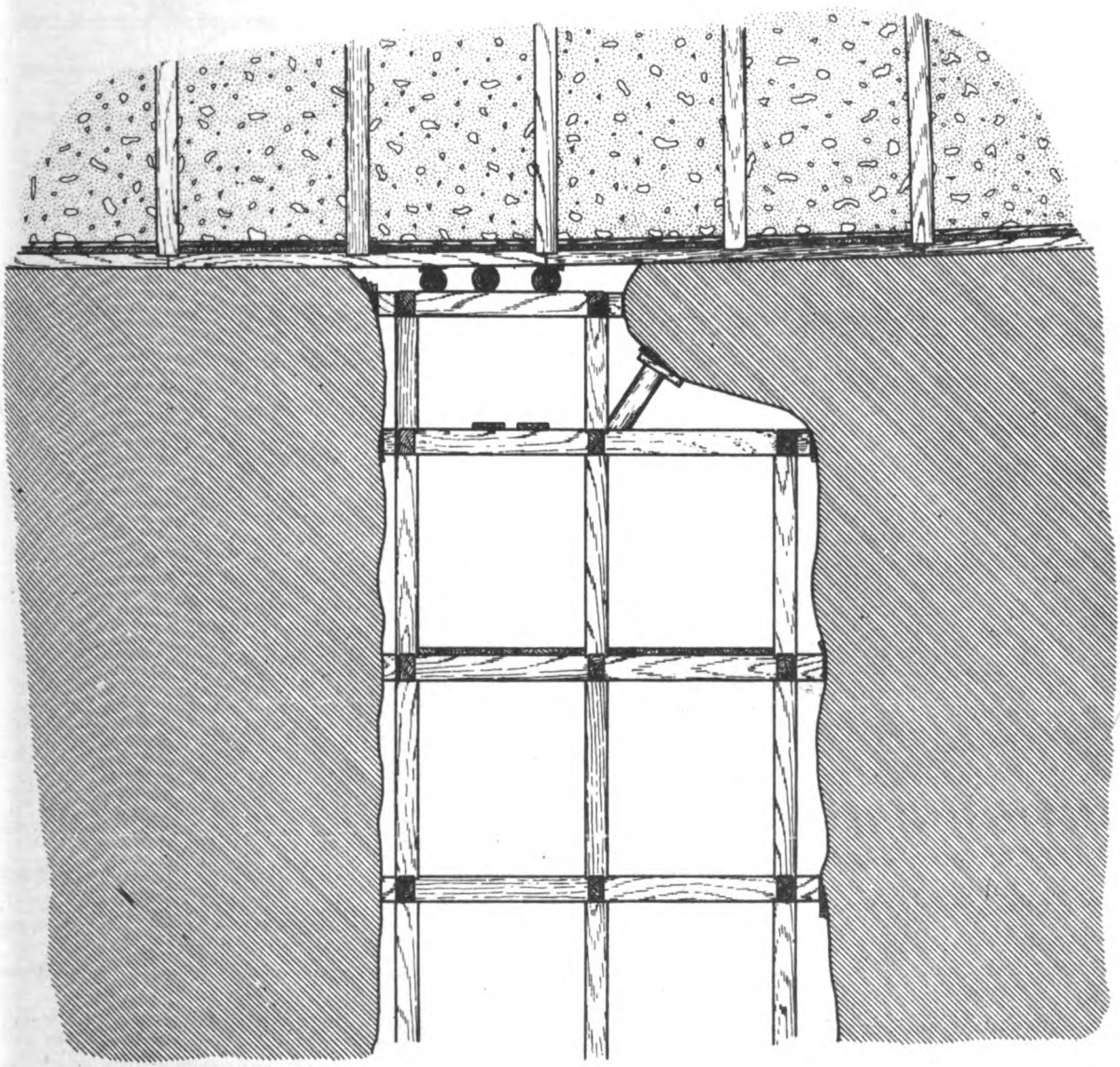

Figure 16.- Method of timbering for catching up sills at Tintic Standard mine

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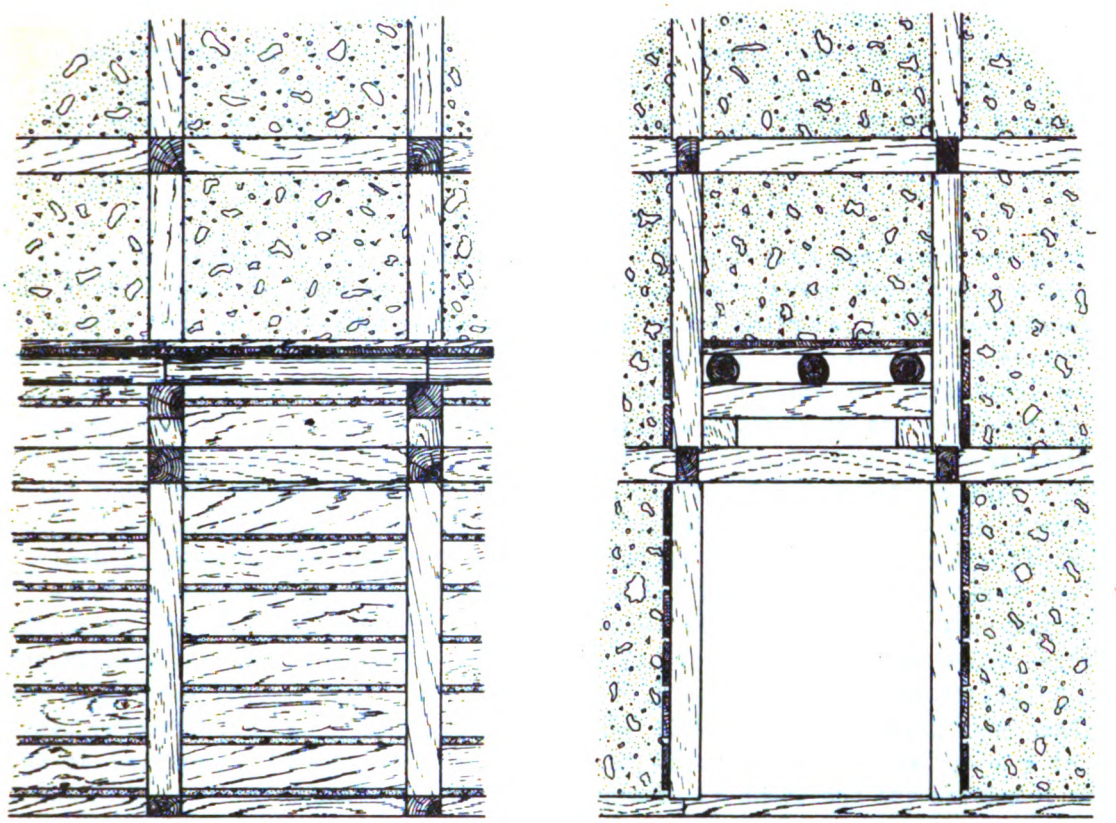
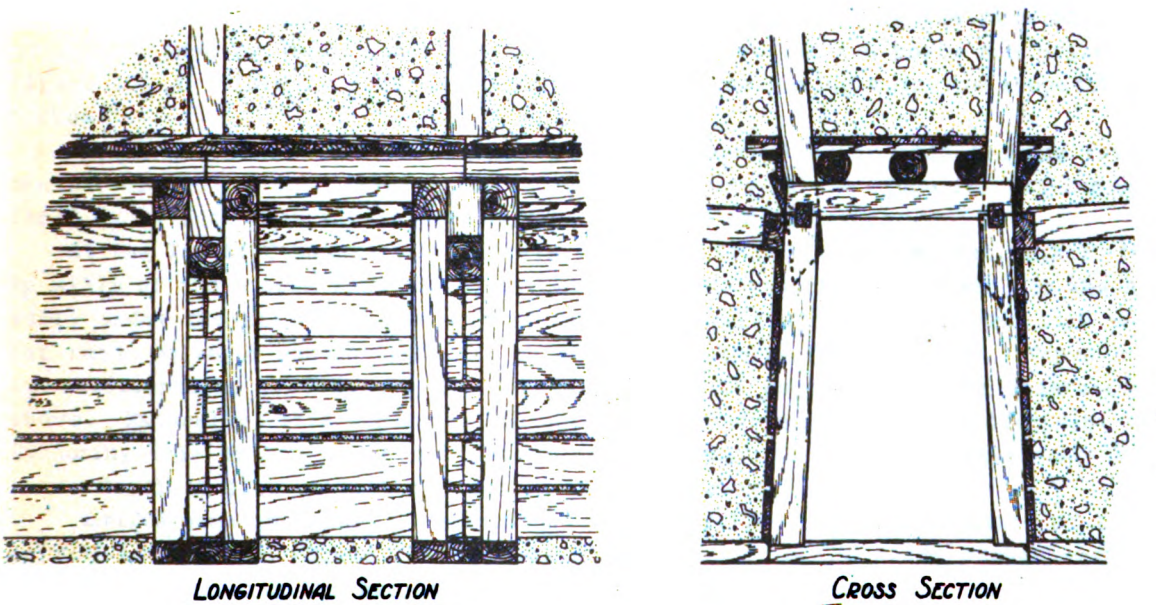


A. Original timbering



B. Method of repairing timbering

Figure 17.- Timbering and maintaining a drift through a filled stope at the Tintic Standard mine

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In ground that will not stand long enough to put in a set the back may be supported and the men protected from falling rock by the use of booms. Usually such ground is mined in sections only one set wide and with one floor open at a time. The booms may consist of I beams or timbers. Hangers of heavy steel are hung on the foremost cap to support the booms, which are blocked under the second cap back. This method of mining is described in greater detail later.

Timbermen working in pairs usually take the timber into the stope and place the sets. Where heavy timber is handled, as at the Morning mine, other men in the stope assist the timbermen in getting it to the place where it is to be installed. At some places the miners themselves act as timbermen and place the sets as soon as room is made. At still other places the men in the stopes do the work at hand whether it is timbering, drilling, or shoveling.

The method of timbering in heavy ground is illustrated by the practice at the Tintic Standard mine.[16] At this mine the length of the section is from the footwall to the hanging wall and the caps are placed parallel to the footwall. The ends of the caps are against the gob of adjoining sections. In the method of framing sets at this mine the caps have a 4 1/2 inch bearing on the 9 by 10 inch posts, while the bearing of the girt is but 1 inch (fig. 4, E); therefore, settling of the fill is not as likely to disconnect the sets at the tenons as if the caps were placed at right angles to the footwall. When angle braces are necessary they are always placed from the gob line to the side of the stope, which puts them on the caps (see fig. 14, A). If the center line of timbers starts riding, diamond braces are used (see fig. 14, B). This again makes use of the caps. Stulls, when used, are always placed on the caps. In general, caps placed at right angles to the gob are in position to give the best results when additional timbering must be done, and the strongest member of the set bears against the gob. Blocking of the sets is always done at the joints of the timbers directly in line with the ends of the caps and braces. No other blocking is allowed until the section is ready for lacing. Just before lacing is nailed on, blocks are placed from the center of the outside line of posts to the solid. These center blocks help to keep the posts in place when the stope is filled, especially when one of the joint blocks has dropped out. They also prevent breaking of the posts by side pressure from within the sets.

Before taking out the ground to make room for a set along the side of a filled stope an 8 by 8 inch by 12-foot stringer is placed against the gob posts and braced as shown in Figure 15, A. This is done to prevent the gob from moving when the supporting ground is broken.

Round poles are used for bridge and stull work, 2 by 12 inch lagging for floors and chutes, and 2 by 6 inch lagging for lacing the corners of the stope for filling (fig. 15, B). The 2 by 12 inch flooring is used to lace the rest of the stope.

At the Tintic Standard the following has been found to be the best method for catching up sills of the stopes when mining is being done underneath: The posts for the sets immediately under the sills are cut so that there is enough space between the caps and the sills for round poles or square timber to be wedged in tightly (see fig. 16). These round timbers lie horizontally from cap to cap and in position to support the sill underneath the posts above. Naturally, this can be called only a temporary support, as filling must soon follow. By using this method it is not necessary to attempt to place the square-set stope on the lower level to line up with the one on the level above.

Drifts sometimes must be maintained through filled stope . A method of timbering such drifts is shown in Figure 17. To allow repair work to the drift timber without removing filling or reducing the height of the drift, bridging is placed as shown in Figure 17, A.

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[16] - Wade, James W., Mining Methods and Costs at Tintic Standard Mine, Tintic District, Utah: Inf. Circ. 6360, Bureau of Mines, Oct., 1930, 21 pp.

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After the filling has stood for a period, and unless repair work is done, the posts may break and allow the filling to run into the drift. It has been customary to replace broken posts and place a doubling-up post under the caps. From experience at the Tintic Standard it has been found better to place a tunnel set on each side of the set with the broken post, making sure that the tunnel sets support the bridging on top and the gob lacing on the sides (see fig. 17, B). The broken post is then cut out and not replaced. If the gob must be maintained in good condition for a long period, it is better to put the tunnel sets in before the stope posts break. A direct line of timber extends from the hanging wall through the gob to the stope posts on the sill. When the sill post is cut out, the line of posts above will be pushed through the waste fill until they cease to carry any weight and become merely a part of the fill. Thereafter the only movement of these upper timbers is with the fill itself. It is sometimes necessary to cut the posts of the first floor above the sill two or three times as they push down into the drift.

In narrow, regular veins square-sets are sometimes placed with the caps normal to the walls. Figure 18 shows the practice followed in 1925 at the Plymouth mine in veins up to 15 feet wide.[17] The advantages of this method of timbering are that waste need not be broken in the walls to stand the sets, as is necessary with vertical sets; the posts can be placed directly over each other; and the caps, being normal to the walls, resist the weight better. The main disadvantage is the sloping floor, which makes shoveling difficult and on which cars can not be run for removing the ore or placing the filling.

As stated before, in placing stringer sets in stops less than 18 feet wide the ends of the caps (stringers), which are the main members of the sets, are blocked directly against the walls. Further support to the caps is afforded by the posts and girts. The blocking, which crushes before the cap breaks, allows the stress to be relieved and usually protects the cap until the stope is filled. At the Morning mine at least 18 inches of blocking is used at the ends of the caps (fig. 19). This blocking or "basket heading" is built of pieces of lagging and a 3-inch internal opening is left in the heading. When side pressure has closed this gap it is time to change the blocking.

Stringer sets have an advantage in extremely bad ground in that caps can be placed and the walls blocked before the complete removal of the ore from the space to be occupied by the set.

Methods of placing timber e further discussed under "Square-set Stoping."

Sill Timbers

The main function of sill timbers is to facilitate the extraction of the ore immediately under the sill sets when mining up from below. In particularly soft ground sills are needed to supply a firm bearing for the posts and to keep the sets in alignment. As stated before, a sill is at least two sets in length. Although sills are generally used, they are left out at some mines, as it has been found that they rot out or are shifted before the underlying ore is mined. Moreover, it has been noted in many cases, especially in strong or firm ore, that the timber at the bottom of the completed stopes can as easily be caught up when the sills have been omitted as when they are used.

Braces may be used between the posts to prevent them from being displaced at the bottom by blasts. By the time the stopes are worked through to the level from below, the gob will have consolidated enough so that there is little likelihood that the posts will swing if a brace is knocked out while coming up under the stope.

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[17] - Arnot, Stanley L., Mining Methods in the Mother Lode District of California: Tech. Pub. No. 1496-A. Issued with Min. and Metall., Sept., 1925.

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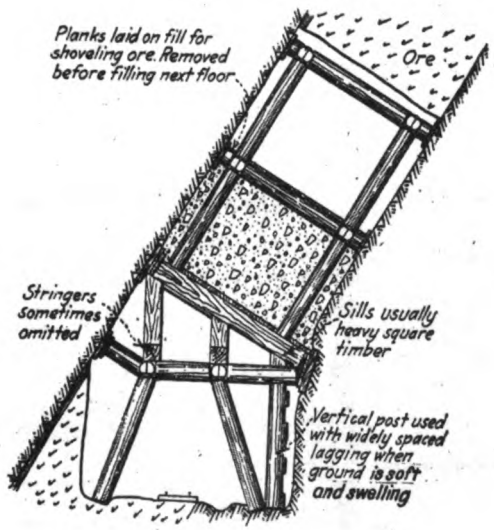
Planks laid on fill for shoveling ore. Removed before filling next floor
Ore
Stringers sometimes omitted
Sills usually heavy square timber
Vertical post used with widely spaced lagging when ground is soft and swelling

Figure 18.- Inclined stope sets used in narrow veins at Plymouth mine

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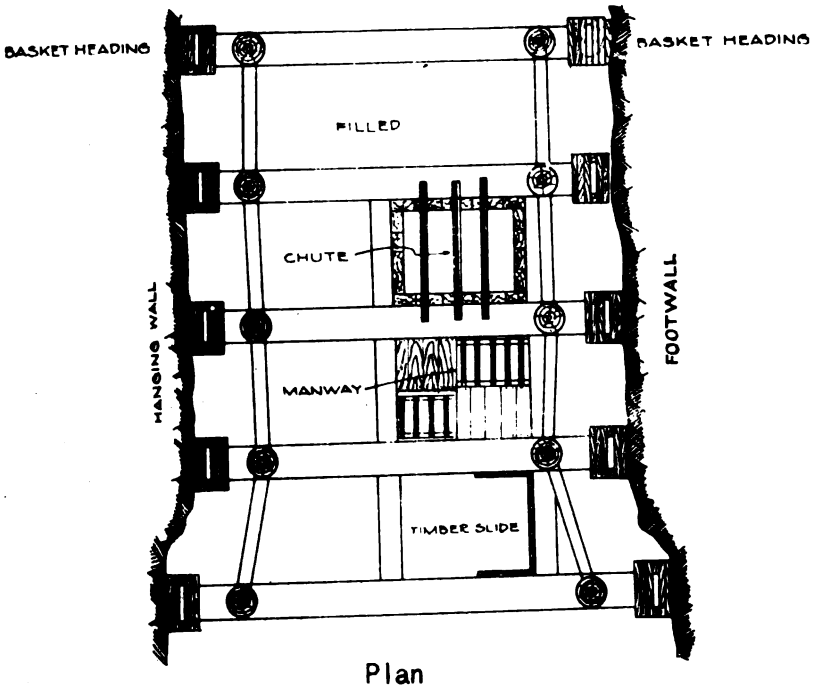
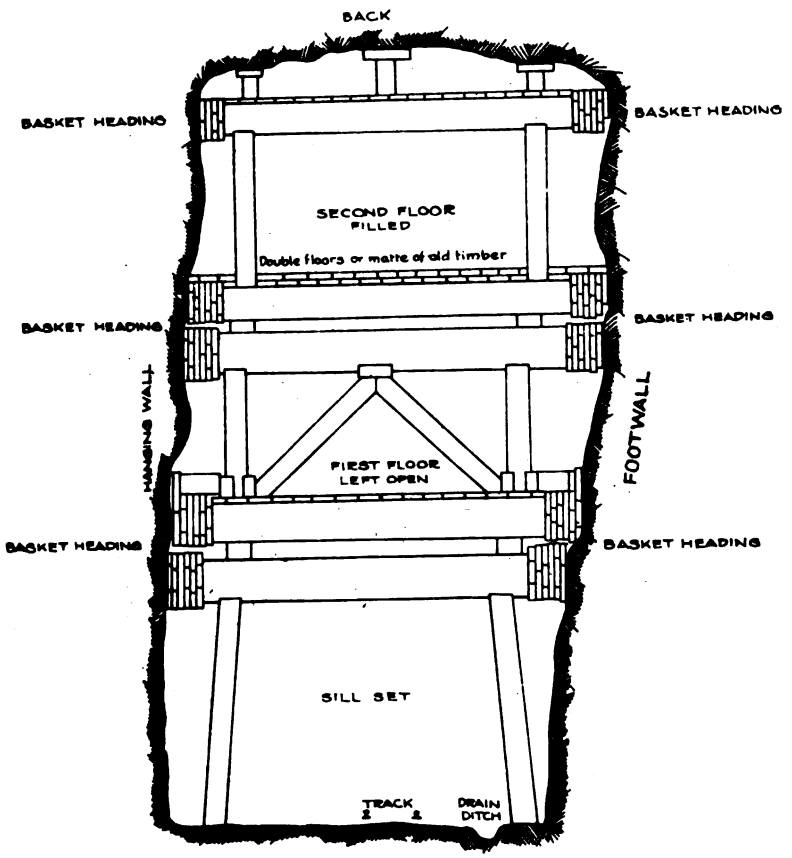


Plan



Elevation

Figure 19.- Method of placing stringer sets at Morning mine

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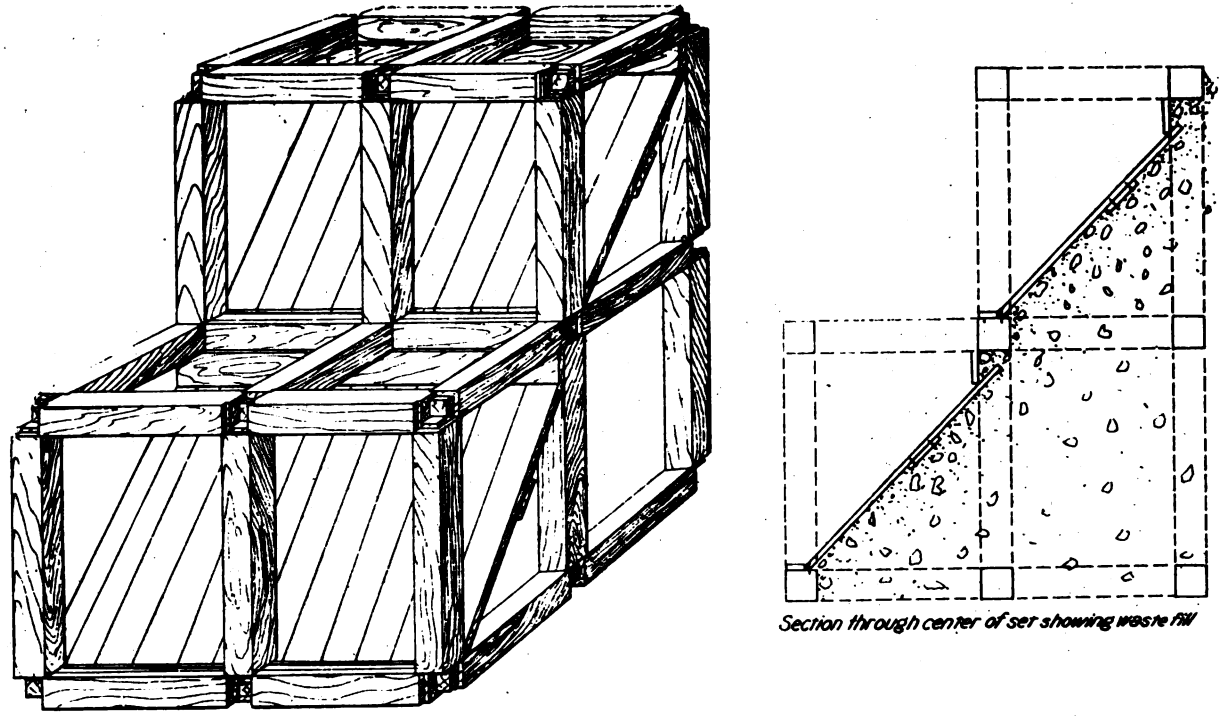

Figure 20.- Method of flooring in inclined square-set stopes at the United Verde mine

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In starting a stope the ground at the bottom of the sill floor is seldom broken deep or evenly enough so that a sill can be laid without considerable digging and the shooting of an occasional "pop" hole.

When made of square timber, posts can be placed in the correct position by the timbermen, when sills are not used, by measuring from the sets already in place. With round posts this procedure can not be as easily followed, as the posts are usually of varying sizes. In this latter case it is generally necessary to estimate the position for the post. After it is stood and the caps and girts placed the set must be shifted into the correct position. This work requires extra time.

The size of sill timbers varies at different places. Usually with 10 by 10 inch timber a 6 by 10 inch sill would be used. At the Ground Hog mine 10 by 10 inch sills are placed from wall to wall on 5-foot centers.

Flooring

Flooring is nearly always laid on the sill floor to hold the waste when coming up from underneath. Poles and old timber may be used to reinforce the flooring. The flooring is laid on sills, when the latter are used; otherwise it is placed on special sheeting put down for the purpose. In a few places where the fill is compacted to such an extent that it will not run when coming up underneath, the flooring may be omitted.

After filling a section of a square-set stope, plank flooring is laid on the sets above to keep the ore from mixing with the waste. Where the rill system is used the flooring must be placed at an angle. The method of placing flooring in inclined square-sets at the United Verde mine is shown in Figure 20.

Flooring in stopes usually consists of 2 or 3 inch plank; occasionally 4 or 6 inch timbers may be used. The flooring is retrieved for reuse; damaged boards generally are used for gob lagging.

Sill Floor Practice

In veins only one set wide the ore must, of course, be silled out on the drift level. Where this is the case the sill posts usually are from 1 to 2 feet higher than the regular stope sets. Either drift sets or regular stope sets with long posts may be used. The extra height is needed to allow room for chute mouths and "doubling-up" sets to brace the sill floor timbers if they should take weight.

In wide veins the stope may be silled out to the width of the vein or section to be mined on the level of the drift or on the next floor above (first floor). In some cases more than one floor may be left above the drift before silling out the stope.

When a stope is silled out above the level it is usually so done to afford protection to the haulage ways. The ore adjacent to the haulage way forms projecting shoulders that keep a considerable portion of the weight off the drift timber. In coming up from below, the finished stope can more easily be caught up and the last ore of the lower stope more readily mined when the stope above is silled out on the first floor. The haulage drift provides an opening for attacking horizontally this last ore to be mined. At the Cananea Consolidated Copper Co., Cananea, Sonora, Mexico, the ore is silled out 11 feet above the floor of the drift. This ore is later extracted by top-slicing.

Where the ore stands well under pressure or the vein is relatively narrow, the advantage of silling out on the first floor is less apparent; in such cases the general practice is to sill out on the haulage level.

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Usually the row of sets immediately above the haulage drift is not filled, or is only partly filled, in order that repairs may be made to drift timbers without disturbing the filling. Figure 21, B, shows the method of supporting the filling above haulage drifts at the Black Rock mine at Butte.[18] Figure 21, A, shows the practice in wide veins at the Argonaut mine.[19] In 1930 silling off for stoping operations was done at the Black Rock mine on the first floor above the level. In starting a stope, "sheeting caps" were placed and blocked about 14 inches above the sill cap. A short piece of lagging was placed under each end of a cap to hold it up until the side weight was sufficient to hold the cap in position. When the second floor of the stope was completed, sheeting poles were laid across the caps and scrap timbers placed over the sheeting poles to hold the waste fill. A similar procedure was followed if the stope was silled on the level, in which case the sheeting was carried on braces between the bottoms of the posts.

At the Argonaut, in some cases instead of placing the regular stope sets directly above the drift sets, a system of long caps on stringers is used to support the stope filling, as shown in Figure 21, A. The blocks for carrying the stringers are placed on the drift-set caps in line with the posts. Stringers are laid on these blocks parallel with the strike of the vein; the stringers in turn support the long caps which extend from wall to wall and are held in position by headboards and wedges. Upon the long caps the stope flooring is laid for holding the waste filling. Above the flooring a change is made to the regular stope sets.

At the Argonaut mine,[20] in narrow veins the ore is silled out on the first floor above the drift; this floor, however, is not filled (see fig. 22). The pressure from the walls on the end of sills laid to support the filling is sufficient to hold them in position for the length of time necessary to replace a broken drift set two floors below.

At the Hecla mine the ore is silled out to the walls when this distance does not exceed 18 feet. Any ore remaining in the walls of the drift when the width of the vein exceeds this distance is removed when stoping up from the level below. The first floor is not filled. Timber, 6 and 8 inch round, cut in 10-foot lengths and laid on the caps of the stringer sets, is used for supporting the filling. Waste timber placed on the round lagging makes the bottom tight.

Figure 19, previously referred to, shows the method of silling out at the Morning mine.

At the Page mine[21] 12 by 12 inch sheeting caps are put in 12 inches above the cap of the drift. This permits repairs to be made to drift timber without loss of head clearance. Stope filling is also supported by an extra cap. The first floor directly over the drift is left open to facilitate repair work.

Figure 23, A, shows the method of silling out used at the Anaconda mine at Butte, both in narrow and in wide veins. The method of supporting filling over a wide set in a narrow vein at Butte is shown in Figure 23, B.

Drift sets in driving a drift in a wide vein generally are removed and replaced with square-sets when the drift level is silled out. If regular stope sets are put in while driving the drift they usually are left standing and the stope timber joined onto them. Caps generally are placed normal to the walls; however, if caps run with the strike in the stope they may be placed in this position in timbering the drift.

Figure 8, E, shows the use of tunnel sets in the extraction drift at the Magma mine.

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[18] - McGilvra, D. B., and Healy, A. J., Methods of Mining at the Black Rock Mine, Butte & Superior Mining Co., Butte District, Mont.: Inf. Circ. 6370, Bureau of Mines, Dec., 1930, 16 pp.

[19] - Vanderburg, William O., Mining Methods and Costs at the Argonaut Mine, Amador County, California: Inf. Circ. 6311, Bureau of Mines, Aug., 1930, 14 pp.

[20] - See footnote 19.

[21] - Berg, J. E., Mining Methods at the Page Mine of the Federal Mining and Smelting Co., Page, Idaho: Inf. Circ. 6372, Bureau of Mines, Nov., 1930, 8 pp.

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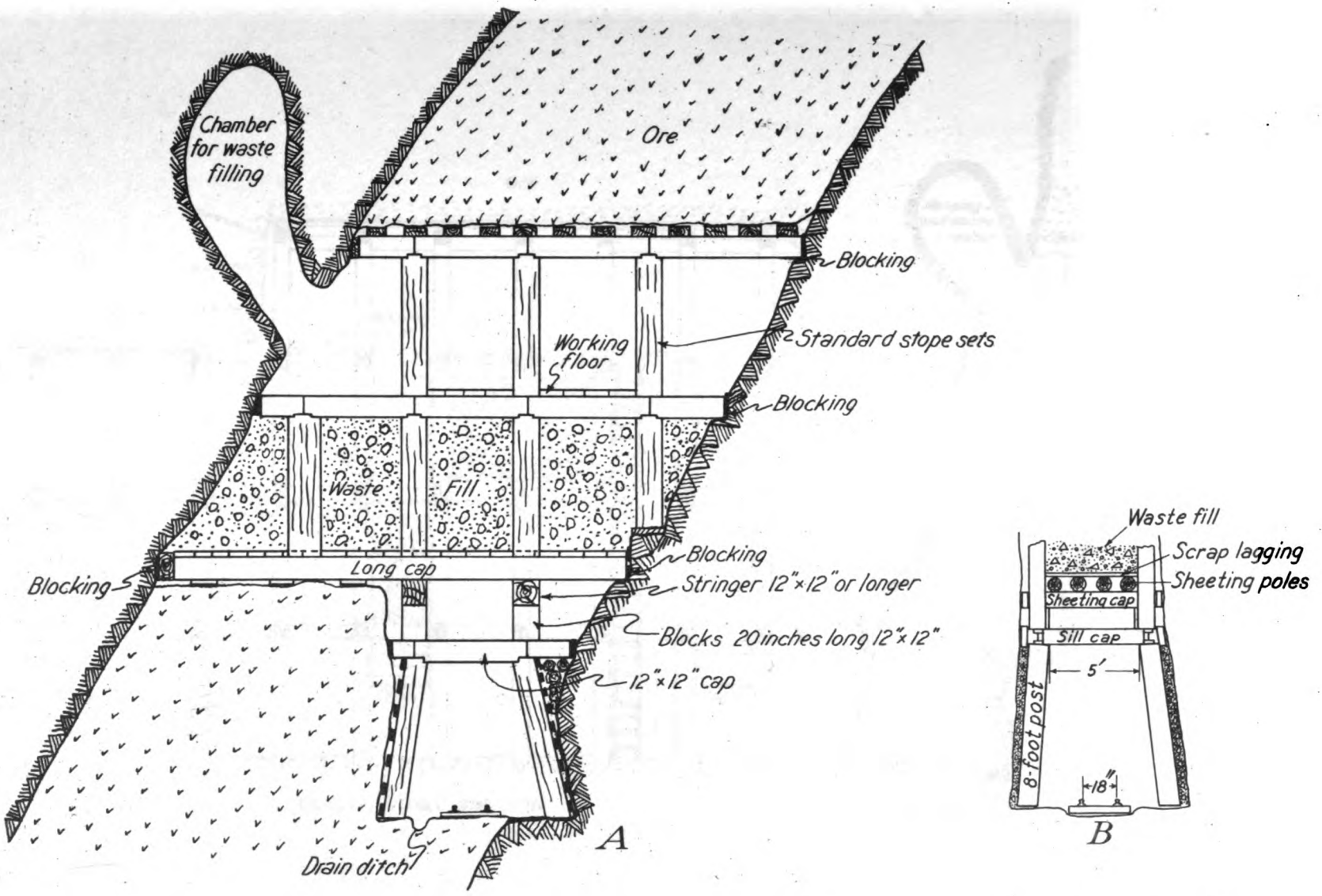

Figure 21.- Supporting filling above haulage drift: A, Vertical section of stope at the Argonaut mine, showing practice in wide veins; B, method used at the Black Rock mine

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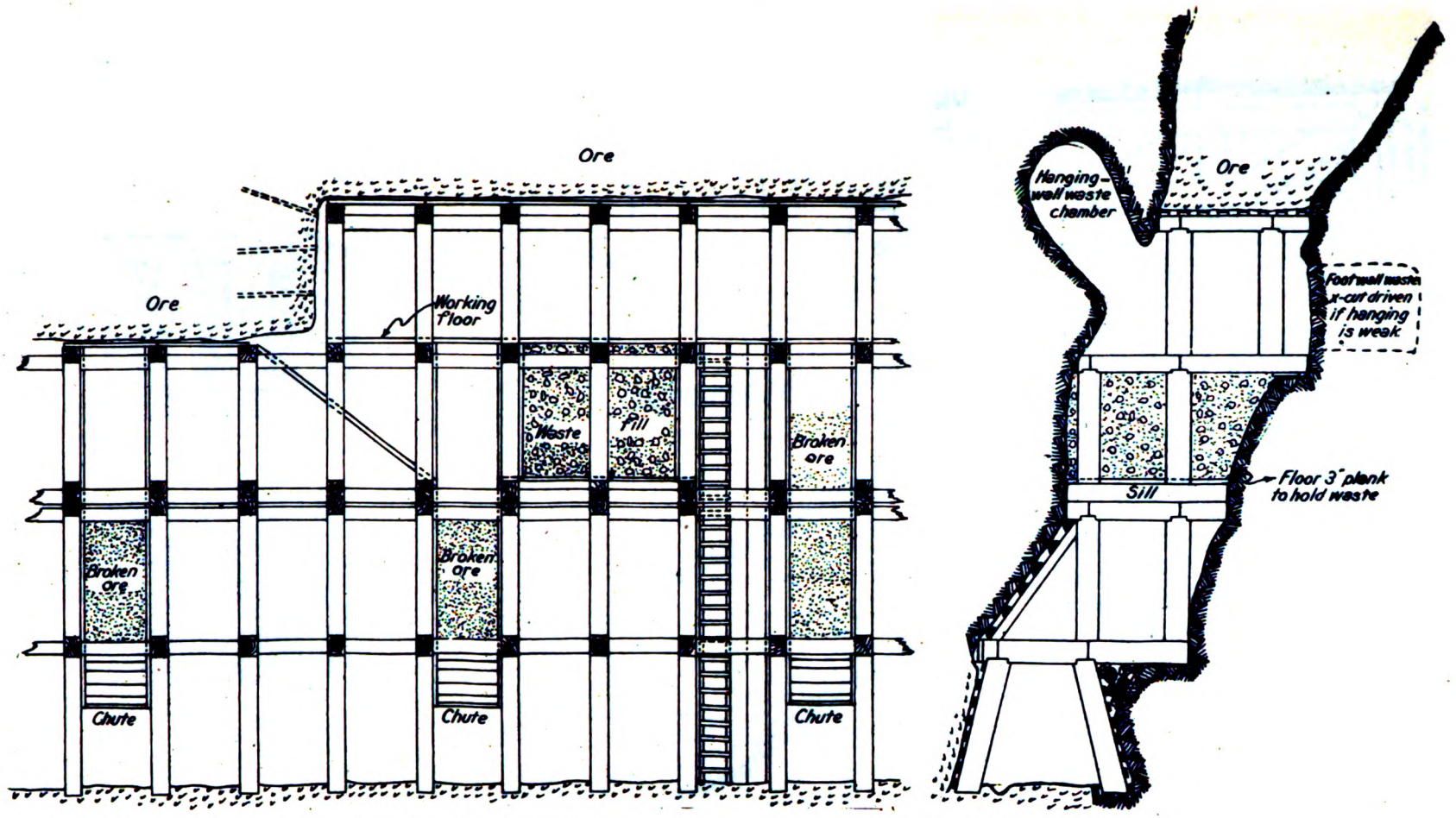

Figure 22.- Vertical stope sections in a narrow vein, Argonaut mine

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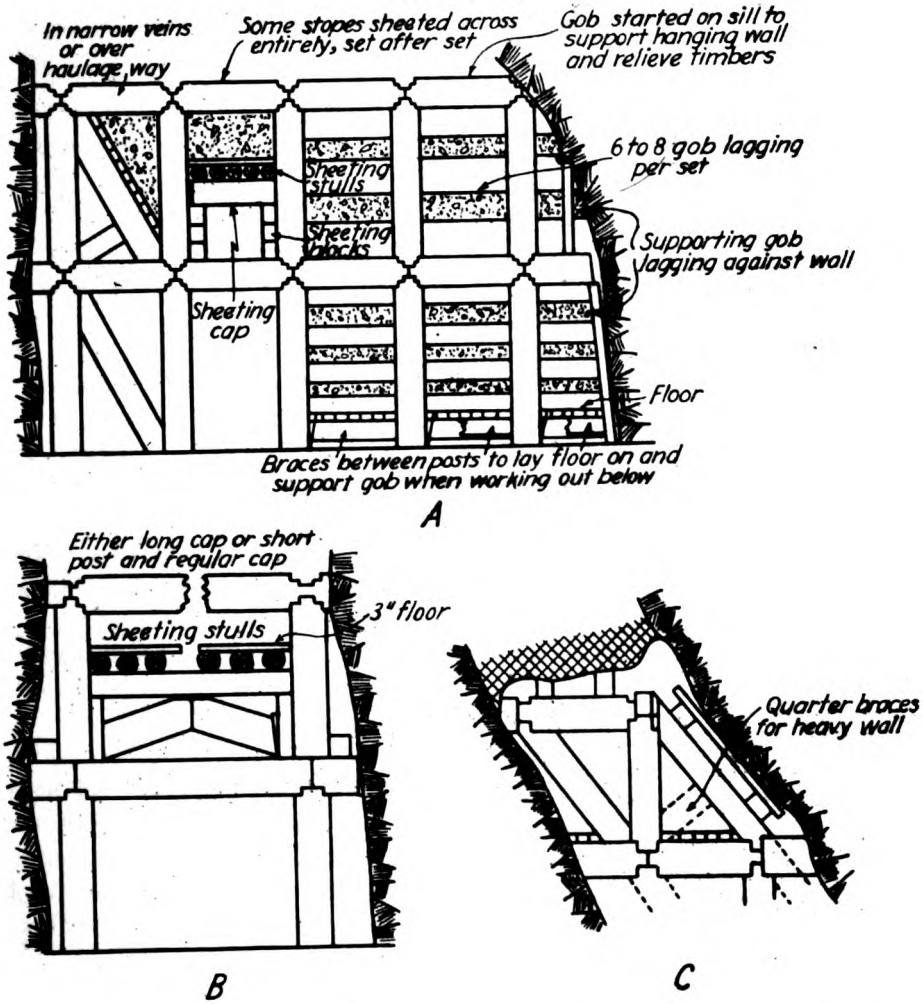
In narrow veins or over haulage way
Some stopes sheeted across entirely, set after set
Gob started on sill to support hanging wall and relieve timbers
6 to 8 gob lagging per set
Sheeting stulls
Sheeting blocks
Supporting gob lagging against wall
Sheeting cap
Floor
Braces between posts to lay floor on and support gob when working out below
A
Either long cap or short post and regular cap
3" floor
Sheeting stulls
Quarter braces for heavy wall
B
C

Figure 23.- Stope timbering at Anaconda mine: A, Method of silling out; B, method of supporting filling over a wide set; C, timbering in square-set raise or stope in temporarily narrow vein

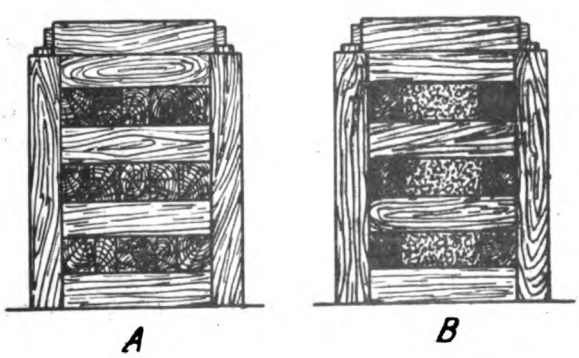

Figure 24.- Types of support for heavy ground; A, Solid timber bulkhead in a square-set; B, rock-filled crib in a square-set

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Square-set Reenforcement

When the limit of the capacity of the square-sets to withstand pressure is reached, the sets may sometimes be prevented from swinging by a system of angle bracing (see figs. 1 and 14). This consists of placing diagonal braces usually against the foot of the posts and inclining the tops so they will fit tightly against the tops of adjacent posts underneath the caps or the girts, depending on the direction of movement. As previously shown, where possible the sets should be placed so that the caps are in the line of the greatest side pressure.

When the square-sets manifest a strong tendency to swing which can not be arrested or prevented by angle bracing, the threatened collapse of the sets may be prevented by cribbing. This consists of crossing alternate layers of round or square timbers of convenient size to form a "pigsty" (fig. 24, B) within the posts of a set; the space within the crib is usually filled with waste rock. The crib may extend from wall to wall through two or more rows of sets if necessary.

Bulkheading may also be resorted to for reenforcing the sets. This method of reenforcement consists of alternate layers of timbers placed close together to form a solid timber support for the back (fig. 24, A). Bracing, cribbing, and bulkheading are frequently used to keep open those parts of stopes that are required for continuing stoping operations.

Filling

Experience has demonstrated that, to mine large orebodies in heavy ground safely and to insure recovery of the ore, the section must be restricted in size and the stopes filled with waste. In the past many large square-set stopes in heavy ground have been lost due to the collapse of the timbering where they have not been promptly filled when the back showed signs of settling.

In extremely heavy ground only one floor and in some cases only one or two sets are left open at a time. At other places in better-standing ground it has been found practical to keep two or three floors open in the regular stoping procedure. An advantage exists in filling as large a space as practicable at a time in that a relatively smaller proportion of the ore must be shoveled, fewer floors need to be laid, and a relatively large proportion of the waste can be run into place without further handling.

Under unusually favorable conditions a combination square-set and shrinkage method may be used. This practice is followed at the Pilares mine of the Moctezuma Copper Co., Pilares, Sonora, Mexico, in some of the square-set sections where the ground is not so heavy as to require close waste filling.[22] Mining operations are carried on to a height considered safe as in straight square-setting, except that the broken ore is left in the stope and only the overbreak drawn off. Mining is then stopped and the broken ore drawn off. Chutes and manways next are built, the stope is filled to the back with waste, and the cycle is repeated.

To keep timber from being pushed out of line or broken by side pressure and to keep settling to a minimum, the waste filling should be placed with care, compacted as much as possible, and all open spaces filled. In heavy ground at the Pilares mine the stopes are filled 12 to 18 inches above the shoveling floor. Although this reduces the headroom, it aids materially in steadying the timber in heavy stopes. The mining floor above is tightly lagged with either 6-inch poles or 6 by 6 inch cribbing.

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[22] - Leland, Everard, Mining Methods and Costs at the Pilares Mine, Pilares de Nacozari, Sonora, Mexico: Inf. Circ. 6307, Bureau of Mines, Aug., 1930, 34 pp.

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The material used for filling has an important bearing on the amount of subsidence. Usually the waste at hand must be used. However, where a selection can be made, a material that packs well should be chosen. Wetting the filling as it is placed facilitates packing and reduces later settling. In many cases, however, water can not be used on account of its detrimental effect upon walls or workings below. Filling will settle to some extent after placing in spite of all precautions.

At the Tintic Standard mine, where water can not be used for packing, stopes have settled as much as 7 feet in 120 feet--the distance between levels. To prevent settling in the stopes where subsidence of the overlying rock is serious, stopes at some mines have been successfully filled with sand which has been washed in through pipes.[23] The sand may be used alone or in conjunction with coarser waste. The sand is packed in tightly and after the initial settling the space may again be filled.

Although fine material makes a substantial gob, when it contains talc minerals it may swell and cause trouble if water gets into it. Filling containing an appreciable amount of sulphides (over 3 per cent) should not be used, as the oxidation of the sulphides may cause gob fires. Old timber should not be placed in the fill on account of the fire hazard.

The material for filling stopes may be obtained from development work, prospecting work, sorting in the stopes, from the walls, or it may be run into the stopes from the surface. In some mines the waste is drawn from the mined-out stopes above the places where mining is being done. As a general rule the waste derived from development or prospecting work is insufficient to fill the mined-out portions of the orebody.

Waste rock from stripping operations in the shovel pit and the waste from underground development work is used for filling the cut-and-fill and square-set stopes at the United Verde mine. It consists mainly of diorite and porphyry, some of it being quite fresh and consequently coarse-breaking, with enough fines to fill all voids. This waste is delivered to the various levels through two main waste raises, one directly from the shovel pit and the other from the Hopewell haulage tunnel. Because of the distance that the waste falls in these raises, the top portions of which are purposely kept empty, considerable crushing action takes place; the waste as delivered to the stopes is considerably finer than when dumped into the tops of the raises. From the main waste raises the waste is trammed to the tops of the waste raises leading from the stopes by the same equipment that hauls the ore, and is spread in the stopes.

No effort is made to tamp the waste. The action of the water seeping downward from the drills and the impact of the falling ore from blasting cause a settlement of about 8 inches for each 7-foot layer of fill. Subsequent settling in old stopes is very slight. The result is a well-compacted waste fill which offers very little difficulty in later mining operations in the removal of either the level or vertical pillars.

Methods of filling at other mines are described later.

Gob Lining

Lining is nailed to the inside of those rows of posts which are adjacent to unmined sections to prevent the waste filling from mixing with the ore while mining of such sections is being done. The space between the lagging and the solid ore is usually allowed to fill up with broken ore to give additional stability to the timbering. The lining may consist of 2 to 6 inch lagging or round poles. Waste timber is also sometimes used for this purpose. The gob lining on either side of narrow sections may be tied together with pieces of dis-

[23] - Gardner, E. D., Sand Filling at Ray: Rept. of Investigations 2208, Bureau of Mines, Jan., 1921, 2 pp.

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carded hoisting cable to prevent the sets from being pushed apart, thereby allowing waste to get through into the ore as the next section is mined.

SQUARE-SET STOPING

General Discussion

Although any system of mining by which the excavation made in stoping is timbered with square-sets is termed "square-settling" or the "square-set method of mining," the manner in which the orebody is attacked varies considerably. The method used depends mainly upon the size and shape of the orebody, the intensity and direction of the ground pressure, the amount of sorting necessary, and the daily demand for tonnage. The existing conditions usually do not allow much latitude in the selection of the method.

For the purposes of describing square-set methods, orebodies may be classified in three groups: (1) Narrow veins; (2) wide veins; and (3) replacement deposits of lenticular or irregular shape.

The variations in square-set mining methods are divided into two general classes: (1) Methods employed where the excavation is not filled after square-setting, and (2) methods employed where filling is used. Very little mining is done without filling; therefore then discussion is confined almost entirely to the latter class. For the purposes of this paper the second group is further divided according to the way the orebody is attacked: Horizontal sections, rill sections, vertical upward sections, and vertical downward sections.

The principal uses of square-setting as an auxiliary method are also discussed separately and are as follows: Recovery of vertical pillars, recovery of horizontal or crown pillars, recovery of caved ground, and miscellaneous uses of square-sets.

Where the length of the section along the strike is greater than that across the vein, it is considered in this paper that the ore is mined by horizontal sections. In case the section is only one or two sets wide, or less than the width of the vein, it is considered that vertical slices are used.

Horizontal sections usually are preferred to rill sections where much sorting of ore is required; the necessity for close sorting may also in some cases make horizontal sections preferable to vertical slices. The amount of sorting required governs to a considerable extent the stoping details as well as being a factor in the choice of the method.

In narrow, steeply dipping veins timbering extending from wall to wall generally can hold the sets open until filled. Where the orebody has a considerable length on both strike and dip, the ore is usually taken out between the walls in horizontal or rilled segments. The sections between manway raises may extend for relatively long distances along the strike. In wide veins, particularly if at a relatively flat dip, pressure that develops on one wall can not be transmitted directly to the other in a straight line through the timbering. Usually in such cases stope sections are taken across the vein. When the ground pressure is from the walls the sections are generally carried up horizontally or in rilled sections; when the ground movement is largely from above, square-set sections are usually carried up vertically. In a weak ore mass the tendeacy is to use vertical rather than horizontal slices. Loose or running ground would very likely be mined in vetical sections, begining at the top and proceeding downward.

Several methods may be used in the same vein, as at the Black Rock mine. In places in this mine where the ore and walls are sufficiently strong the ore is mined by horizontal sections, closely followed by filling. Loose and running ground is mined by underhand stoping, carrying vertical sections dowaward. Ground intermediate between the two foregoing classes is mined by a top-slicing method using square-sets. The country rock is granite,

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which is intensely altered in proximity to the vein. Stoping widths in the vein range from 1 to 12 sets. The dip is 80°. The walls of the vein are usually of talc, which allows blocks of ore to slide downward when undercut. Some of the ore is soft and crumbly, and within the veins the ore often breaks to slips running at right angles to the walls.

In irregular orebodies the intensity and direction of the predominating ground pressure determine to a great extent the size of the stope section and the method of taking it out. Stope sections are usually laid out with the longest dimension along the line of least resistance in order to have a minimum of ground open under the heaviest pressure.

In irregular deposits in heavy ground relatively narrow sections—two or three sets wide and one or two sets high, depending upon the ground—usually are taken out at right angles to the major axis of the deposit. These sections are generally started at the footwall and extended to the hanging wall; they are carried upward one at a time to the top of the orebody or to the level above. Although the sets are taken out horizontally, in effect a vertical slice is taken in the orebody each time a section is advanced upward.

Small sections can be completed in less time than large ones. Decreasing the size of sections has frequently aliminated trouble from wall pressure. In some cases a small section may be worked through between levels without filling, whereas a lar e one would have to be filled as stoping progressed. A stope should be worked out at such a rate that the timbers are relieved as pressure develops; that is, when the floor begins to take weight it is time for the floor above to be started in order to relieve the one below. If the floor has many broken caps or girts it is an indication that the stope has not been worked fast enough. The ground is usually broken about 6 inches above the set, thus allowing some time before the blocking is crushed and the actual weight of the ground comes down upon the timbers of the sets.

Where the demand for tonnage requires mining the ore rapidly, larger sections are frequently more practicable than would otherwise be the case.

A stope section may be from 1 set wide and 1 or 2 sets long up to 50 sets long, depending upon the width of the vein and the ground conditions. Stope sections at the 19 representative mines shown in Table 3 are from 1 to 7 sets wide and from 2 to 50 sets long. In a narrow vein, mining by horizontal or inclined cuts or slices, a section may be the same size horizontally as the stope. In large orebodies several sections may be mined concurrently in a stope.

The practice at some places is to mine vein deposits by the stope-and-pillar method. The stopes are taken out by shrinkage, cut-and-fill, or square-setting methods, and then the intervening pillars are extracted by square-setting. The pillars are usually more or less fractured or crushed, which makes mining them expensive and sometimes dangerous. Although the first sections are mined more cheaply than when no pillars are used, extracting the ore in pillars is usually more costly and the resulting over-all cost may be higher. The present tendency in veins is away from this practice, except in unusual cases.

At the Pecos mine the orebodies are mined out in sections, the length of a section depending on the width of the vein and on ground conditions. During the first two years of operation, in wide veins, stope sections were from 15 to 60 feet long, with 15-foot pillars between. More recent practice is to cut initial stopes 30 feet long, spaced 100 to 150 feet apart, with extraction chutes in both ends of the sections. After these initial stopes have reached or nearly reached the level above, new sections, usually about 15 feet long, are started on one or both sides of the stopes, using the former extraction chutes for fill raises. Pillars occur only where two stope blocks come together.

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General data on mines using square-set methods of mining are shown in Table 4. Stoping data are shown in Table 3.

Stoping Without Filling

The practice of square-setting without filling is illustrated at the New Idria mine in San Benito County, Calif.[24] In common with other quicksilver deposits the distribution of the ore is erratic and to follow the ore a flexible system of mining must be employed.

As an orebody is opened up it is followed with a drift through the full width of the ore. After the lateral limits of the orebody are reached a stope is started.

If the dip of the orebody is sufficient to allow the workmen to stand without a working platform or is of such a thickness (not over 10 feet) that the ore can be drilled and blasted without using staging, the open-stope method is employed. The square-set method is used in other cases. In mining by the open-stope method the ore is blasted directly on the floor of the level and then shoveled by hand into 17-cubic foot mine cars.

In using square-sets, silling off is done at the level and sill timbers are used under the posts. The framing details for the square-set timbers are shown in Figure 4, F. The sill sets are the same as the regular stope sets.

Each square-set stope is advanced upwards horizontally one floor at a time for the entire plan area of the stope. Only sufficient ground is broken at a time for standing either one or two sets. Ore chutes are carried upwards in the square-sets at intervals of about 40 feet. The ore chutes are lined with 3-inch plank.

The ore is blasted onto a floor consisting of 3-inch plank which is laid one set below the back of the stope. The broken ore is shoveled into the chutes by hand.

The square-set stopes are not filled with waste. The timbering is used primarily to provide a working platform; support for the walls and orebody is secondary. The orebodies are extremely irregular and the use of square-sets permits prospecting the walls and following the irregularities of the ore with little difficulty, whereas with shrinkage stopes this could not be done satisfactorily. The square-set stopes in present mining operations vary from 6 to 15 sets in length and 4 to 12 sets in width. The square-sets are not framed primarily to withstand pressure from any particular direction. Practically all square-set timbers are removed from the mined-out stopes and used over and over again until worn out or broken in blasting. The walls stand well after the timber is removed.

Stoping With Filling

Horizontal Sections

In Narrow Veins Using Regulation Sets.- As stated before, relatively narrow veins are usually mined by taking out horizontal or rilled sections. The length of the section generally corresponds to the length of the stope. The general method of mining and variations in practice to fit local conditions are illustrated at the Anaconda, Argonaut, and Page mines.

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[24] - Moorehead, W. R., Methods and Costs of Mining Quicksilver Ore at the New Idria Mine, San Benito County, Calif.: Inf. Circ. 6462, Bureau of Mines, June, 1931, 14 pp.

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Table 4.- General data on representative mines using square-set methods of mining

Mine	Location	Kind of deposit	Size of orebody	Dip of orebody, degrees
Anaconda	Silver Bow County, Mont.	Veins in granite	4 to 100 feet wide	Steep dips predominate
Argonaut	Amador County, Calif.	Vein in slate and greenstone	20 feet average width	63 average
Page	Shoshone County, Idaho	Veins in quartzite	1 to 20 feet wide	40 to 60
Pecos	San Miguel County, N. Mex.	Lenses in sheer zones in diorite schist	25 feet average width	70 to 90
Central Eureka	Amador County, Calif.	Veins in slate and greenstone	5 feet average width	50 to 80
Black Rock	Silver Bow County, Mont.	Veins in granite	2 to 120 feet wide	80 average
Hecla	Shoshone County, Idaho	Veins in quartzite	3 to 40 feet wide	70 to 80
Morning	Shoshone County, Idaho	Veins in quartzite	6 to 30 feet wide, average 13 feet	80 to 90
Silver King Coalition	Summit County, Utah	Bedded replacement deposits in limestone	-	20 average
Ground Hog	Grant County, N. Mex.	Vein in granodiorite and diorite porphyry	3 to 25 feet wide	50 average
Magma	Pinal County, Ariz.	Vein in diabase	20 to 30 feet wide	45 to 80
Park Utah	Wasatch County, Utah	Mainly fissure deposits in limestone	12 to 80 feet wide	40 to 55
Cananea (Colorada mine)	Sonora, Mex.	Pipe-like deposit in quartz-porphyry	20 to 60 feet wide for square-set stopes	Vertical
Bunker Hill and Sullivan	Shoshone County, Idaho	Veins in quartzite	35 to 125 feet wide	40 to 50
Old Dominion	Gila County, Ariz.	Veins in sedimentaries	2 to 60 feet wide	60 average
Tintic Standard	Juab County, Utah	Replacement deposits in limestone	Tabular deposits, 6 to 200 feet high	45 to 90
United Verde Extension	Yavapai County, Ariz.	Massive sulphides	-	-
Copper Queen	Cochise County, Ariz.	Replacement deposits in limestone	-	-
United Verde	Yavapai County, Ariz.	Massive sulphides, replacement in schists	300 feet wide average	60 average

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Table 4.- General data representative mines using square-set methods of mining - Continued

Mine	Character of walls	Kind of ore	Amount of ore per ton, cubic feet	Percentage of total production by square-setting	Normal daily tonnage
Anaconda	Soft to firm	Copper, silver	9 to 11	80	10,000
Argonaut	Soft, fractured, weak	Gold in quartz	12.5	100	260
Page	Broken and shattered, swelling	Lead, zinc, silver	9	100	300
Pecos	Soft and loose	Zinc, lead, copper	-	51	600
Central Eureka	Soft, swelling	Gold in quartz	-	100	160
Black Rock	Talc seams, faulted, weak	Zinc, lead, copper, silver, gold	-	100	1,200
Hecla	Sheared and weak	Lead and zinc	-	75 to 100	900
Morning	Sheared and swelling	Lead, zinc, silver	9	100	1,100
Silver King Coalition	Strong to weak	Lead, zinc, silver, gold	-	100	500
Ground Hog	Fractured and crushed, weak	Zinc, lead, copper, silver	9	75 to 100	130
Magma	Crushed, weak	Copper, silver, gold	10.5	-	830
Park Utah	Brecciated and weak, faulted	Lead, zinc, silver	-	Nearly 100	550
Cananea (Colorada mine)	Solid	Copper	9.8	12	1,600
Bunker Hill and Sullivan	Weak	Lead, zinc, silver	-	About 80	1,400
Old Dominion	Soft to firm	Copper	12.5	21	1,500
Tintic Standard	Soft and brecciated, weak	Lead, silver	-	100	300
United Verde Extension	Hard to loose, swelling	Copper	-	Nearly 100	1,200
Copper Queen	Fairly strong	Copper	9 to 11	55	1,000
United Verde	Variable	Copper	7.9 - 10.3	27	2,400

1 - Excluding porphyry ores.

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A typical example of mining a narrow vein by horizontal sections at Butte is shown in Figure 25.[25] The drift under the stope is timbered with standard "Rocker" sets (fig. 5, D) with 8-foot 8-inch posts. As the drift is advanced offsets are cut into the footwall at every fifth or sixth set (fig. 25, sec. AA). Raises to connect to the level above are started in every third or fourth offset. The first raise is put up to the level above for ventilation before stoping begins; a second raise is started at the other end of the block to be stoped and is usually run while the first two floors of the stope are being taken out. The raises are timbered with standard square-sets and contain two compartments, one for a manway and one for a waste chute.

The ore of the first two floors is blasted on lagging laid on top of the drift sets. It is shoveled or dropped into cars through openings made in the floor by removing pieces of lagging. The two over the off-sets in the drifts are of 10 by 10 inch timber and the other sets are of round timber. The timber for the first few floors is hoisted into the stope by means of a portable air hoist. After a raise is completed timber is lowered through it for the nearby section of the stope. After the first two floors are mined and timbered, sheeting is put in to hold the filling and the intermediate ore chutes and manways are built. A covering of 4 by 10 inch lagging is laid in the second floor and stoping proper then begins on the third floor. The first set of this floor is started at a raise by drilling from below. The ore is blasted down on the second floor and shoveled or wheeled in wheelbarrows into the nearest chute. Any waste is sorted out and dropped through the floor. Two floors are usually kept open at a time.

Filling in excess of that sorted from the ore is drawn from the waste raise through temporary chutes placed at each floor as stoping progresses. The waste is allowed to run from the raise into the first few sets and then is leveled off by hand. For subsequent filling the waste is drawn into cars and transferred to the place needed. Although it is not considered good practice because of weakening of the walls, 45° raises are driven into the footwall for filling in isolated cases where a raise has not been driven to the level above.

Subsequent blocks are mined in the same manner; the next stope usually is well under way before the first one is finished. Ground conditions govern the closeness with which one block can follow another.

Although the same general scheme of mining is followed at the Argonaut mine as at Butte, variations in practice occur. One of the main differences is in the use of slides, as the ore does not need to be sorted.

Figure 22 shows the manner of mining in narrow parts of the vein at the Argonaut mine. A vertical section of a stope in a wider portion of the vein is shown in Figure 21, A. Stoping is carried upwards in sections about 100 feet long, the usual distance between two consecutive manways.[26] Several stopes are generally mined at the same time; the back of each succeeding stope is several floors lower than the preceding one.

Chutes for drawing ore from the stopes are built in every fifth drift set; that is, at intervals of 25 feet. Manways are carried up as the stope advances. Practically all the vein material in the ore shoot is mined without sorting. No pillars are left.

Because of the conditions that arise in mining in such heavy ground, the manner of removing the ore is varied according to the mine foreman's judgment. Generally only enough ground is broken at a time for standing one set of timber. When one floor is mined out across

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[25] - Bicknell, H. L., The Butte System of Square-St Mining: Compressed Air Mag., April, 1922, p. 113.

[26] - Vanderburg, William O., Mining Methods and Costs at the Argonaut Mine, Amador County, Calif.: Inf. Circ. 6311, Bureau of Mines, Aug., 1930, 14 pp.

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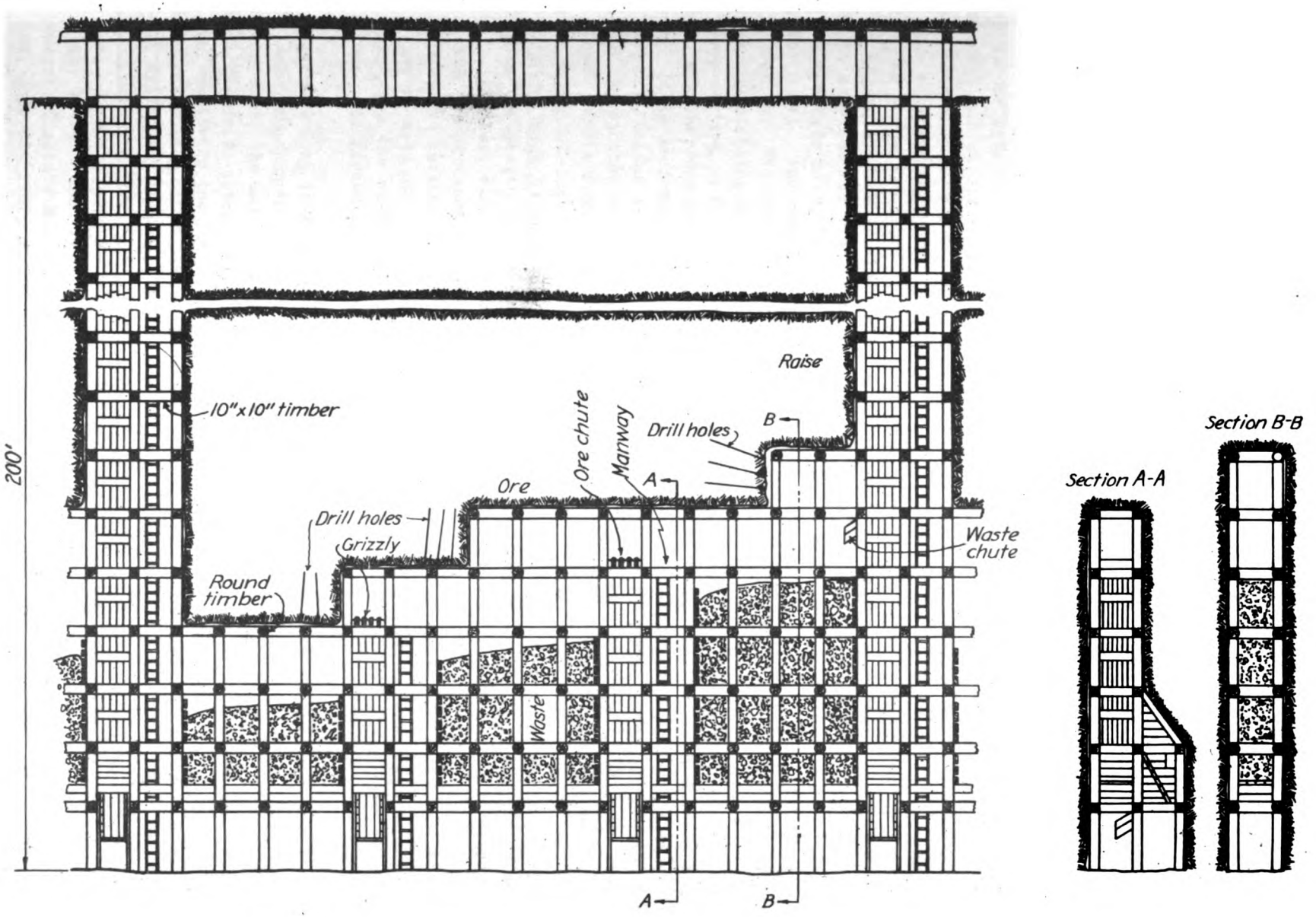

Figure 25.- Typical method of mining a narrow vein by horizontal sections at Butte

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the width of the vein and the length of the 100-foot section, another one is started. The ore breaks fine enough in blasting so that it can be drawn from the chutes very readily without hanging up. When possible the ore is diverted into the chutes by wings built of plank in the square-sets. The ore that can not run by gravity into the chutes is shoveled by hand.

Filling with waste is carried on simultaneously with stoping so that only one floor is open at a time. The bottom of the open floor is covered with plank. The gob is held in position at the ends of a section with 2 or 3 inch lagging nailed to the sides of the raises adjacent to the waste. Filling is obtained by driving inclined chambers into the hanging wall, or if the hanging wall is weak and has a tendency to cave, filling is supplied by driving crosscuts into the footwall. The waste is run into stopes as much as possible by gravity and the final leveling off of the fill is done by hand.

At the Page[27] mine stopes are carried up in single blocks about 250 feet long and are mined in one lift for a distance of 300 feet. The vein on both strike and dip pinches to a mere gouge and swells at times to a maximum thickness of 20 feet; it has no well-defined walls. The enclosing rock consists of heavy and swelling quartzite.

The main working chute raises each contain two compartments and are spaced 140 feet apart. Ore passes are spaced 35 feet apart and are cribbed. Chutes are occasionally so flat, due to irregularities in the dip of the vein, that it becomes necessary to flood them with water to make the ore run. A minimum of 40° is allowed in chute construction.

At the Page mine the ground is so heavy that timber must be placed as soon as room is made for a set. Any open space above every set is tightly cribbed with slabs as soon as the set is put in. The slabs act as a cushion for the stope timber until the ground pressure is relieved by starting a new floor.

Some sorting is done; the broken material is either put in the ore chute or rejected for waste. Wheelbarrows are used except where the ore can be blasted or run by gravity into the chutes. It is desirable to keep stopes filled to within three floors or less of the back of the stope. Filling is obtained from crosscuts into the footwall; these are started 5 by 7 feet and the section of the face enlarged to 8 by 12 feet at a distance of 25 to 30 feet from the stope. Waste from these crosscuts is placed in fills by the use of single-drum tugger hoists, using 3/8-inch cable and the ordinary drag scraper.

In Wide Veins Using Regulation Sets.- As stated before, in veins of which the width is less than the length of the section, horizontal sections are generally advanced along the strike. In other veins of which the width is greater than the distance of the section along the strike the sections are taken across the strike.

Floors are customarily started at raises, which usually are on the footwall. After the first line of sets on a floor is in, the section may be advanced along or across the strike, depending upon the width of the vein, the length of the section on the strike, and ground conditions. In ground that stands well the same general plan as in narrow veins may be followed.

Square-setting in wide veins is well illustrated by the practice in Butte, at the mines of the Anaconda Copper Co. The same general method of mining is followed in wide veins as in narrow ones; the main difference is in the length of the stope section.
Although the drift floor is silled out in some cases, this is not the usual practice. Crosscuts are run toward the hanging wall at the chute sets when the vein is wide enough to require draw points other than at the footwall drift. In wide veins both footwall and hanging-wall drifts may be run. The method of silling out is shown in Figure 23, A and B.[28]

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[27] - Berg, J. E., Mining Methods at the Page Mine of the Federal Mining and Smelting Co., Page, Idaho: Inf. Circ. 6372, Bureau of Mines, Nov., 1930, 8 pp.

[28] - Harrer, Clarence M., Square-Setting in the Butte District: Eng. and Min. Jour., vol. 124, July 30, 1927, p. 167.

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Raises are spaced according to the length of the stope, the distance between levels, the nature of the ground, the use to which the raise is to be put, and the requirements for ventilation.

In heavy ground in wide stopes the raises may be 25 feet apart, while in better-standing ground the distance may be as much as 75 feet. The latter, however, appears to be too great a distance for efficient ventilation in wide stopes. The raises are put up on the footwall.

Figure 13, A, shows the method of mining a wide stope with a relatively flat dip. The footwall square-set raise prospected the vein in advance of mining. The ore is allowed to fill in to angle of repose in timbered offsets in the vein.

In advancing the section from the footwall to the hanging wall in ore that stands well, enough ground to stand two or three sets of one floor may be blasted as one round. In the heaviest ground only space for one set is broken at a time. The floors are taken out advancing from a raise. The length of the section is, of course, limited by the distance apart of the waste raises. The ore is broken and removed and the timber placed in much the same manner as in narrow veins.

Lenses or horses of waste occasionally occur in stopes. If not too large the waste is shot down and used for filling. If a body of waste is too large to be used for filling, it is left in place and the stope then worked in two or three sections with a crew of miners in each.

Where the raises are close together—for example, 25 feet apart—the filling from the waste raise is allowed to run to the angle of repose into the stope. The pile is then leveled off by hand and floors are laid. Waste is then allowed to run on the floor and is shoveled into adjoining sets between chutes from foot to hanging wall. In stopes with wider spacing of waste chutes a car is used, as in narrow veins.

The filling is retained laterally in the stope section by lining the inside of the outside sets with 2 by 6 inch by 5-foot 6-inch standard "gob lagging." These lagging are spaced 2 inches apart. Small poles may be used instead of the sawed lagging. The bottom floor to be filled is prepared as outlined previously. It is important that all flooring be removed and the sets on the hanging wall be completely filled to prevent shifting and breaking of the hanging wall.

Track is laid on lagging spiked between posts, as the timbers are not always in perfect alignment when built up for several floors. The track is removed and the car is hoisted by chain blocks to successive floors as needed.

In heavy ground or where a stope has remained idle for some time the timbers may be split by the settling of slabs of ore. If the timber can not be replaced before advancing, the stope is reinforced by means of doubling-up sets, by using stulls and headboards, or by erecting cribbing or bulkheads.

In many instances side pressure in stopes, even where the stope is filled and the timbers carefully blocked, causes displacement of timbers, which destroys the uniformity of the stope level. Occasionally the stope timbers are so out of alignment as to require the laying of a new sill with stringers on the gob and sill posts. Sometimes special-length posts are necessary to level up the floor above. In the lateral warping of the stopes, the original square-set joints may become so weakened that the timber will not hold up unless hand framed. Settling or swelling of the gob causes additional shifting of timbers and squeezing or crushing in of sills. In such cases laterals and crosscuts to the old sill are often driven to catch up the timbers.

In mining successive floors the routine is the same until within two or three sets of the level above, unless the stope starts to cave, in which event extra care is taken in blasting, keeping up the timbers, and filling up to the shoveling floor. Slabs of ore riding on timber are mined out as soon as possible. One or more manways are maintained in good

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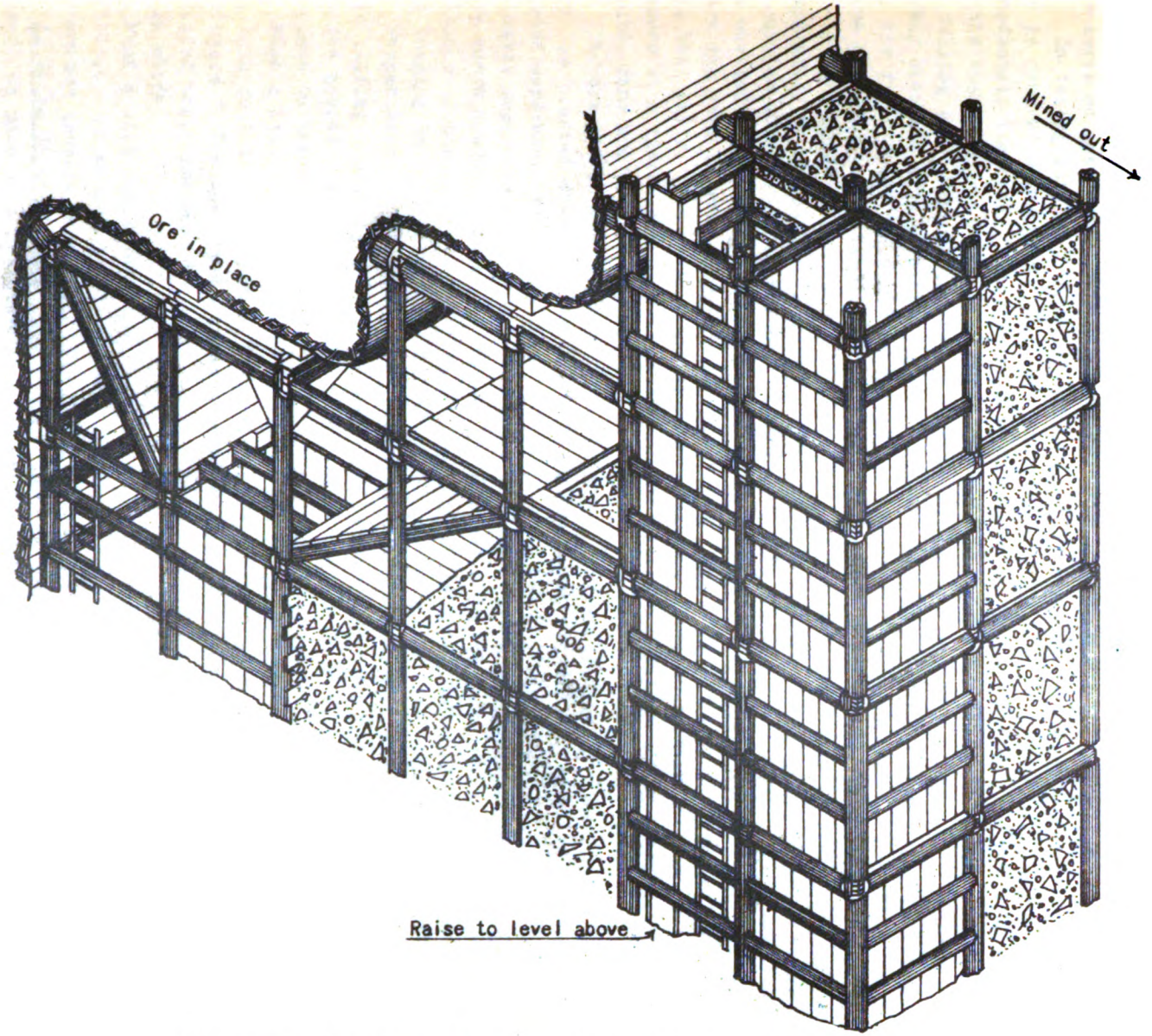

Figure 26.- Section of stope, footwall view, Black Rock mine

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condition in case a hurried exit is necessary. In general a dangerous place can be detected by creaking of the timber and the noise of the working ground. When men are trapped it is not usually from lack of warning but rather from uncertainty as to the time to leave.

In mining out the last floor, care and judgment are necessary to prevent wrecking of the timbering above and the releasing of the filling in the old stope. The sill is reinforced with stringers or bulkheads and all the sill members are braced with stulls. The timbers of one level do not match those of another; hence, the necessity of using stringers.

In taking out the ground, careful, light blasting is practiced, and in some cases the ore is removed by picking. Only one set of ground is taken out at a time, and the space is immediately timbered. Once the regular timber is in, it is essential that all loose members of the timbering on the haulage level be caught up with stringers and blocked. This is done by filling over the regular set and under the sill members with odd-sized timbers and by firmly blocking them in place. When this floor is mined out and all sill timbers are caught up, the floor below the level is filled with waste to the track level. The last floor of a stope may come to the regular set, or sets with short posts may be necessary.

At the Black Rock mine, at Butte, a drift is driven along the footwall of the orebody preparatory to stoping. The drift is timbered with framed sets having 8-foot posts. A stope is carried upwards in short blocks ranging from 4 to 10 sets in length. A chute and a manway are carried at the end of the block and in time serve as a supply raise for the next section. Where the vein is wide, the hanging-wall half of the vein is stoped out first and the footwall half later. The usual practice in stoping is to blast out ground enough for one set of timbers at a time. The caps and posts of the sets are framed alike; occasionally, in heavy ground, caps are used as posts.

The ore is shoveled by hand into chutes or, if clean enough so that sorting is unnecessary, is blasted onto a slide. The waste occurring between the bands of ore is usually blasted separately and dropped directly into the "gob." Where it is impracticable to blast the waste separately the round is blasted and held on the mining floor and sorted by hand. Extra waste needed to complete filling is obtained from the level above. Temporary flooring is laid over the entire area of each floor and is taken up before filling is run in. Two-inch lagging is used to retain the waste fill on the end of the stope.

Stopes over two sets in width usually require bulkheads in addition to square-sets and waste filling. Usually a crib bulkhead, built with stope posts and braces, is sufficient. When the ground over a bulkhead is mined, the bulkhead is moved up a floor and waste put in its place on the floor below.

When a block has been mined to within two or three sets of the level above, a line of sets from foot to hanging wall is carried upwards. The sill timbers above are caught with "stringers." The next line of sets is then mined in the same manner. The first line of sets is filled while the second line is being mined. Small poles are used to hold the waste filling in place.

When a sill floor is stoped from below it is usually abandoned and no attempt is made to fill it. If necessary, bulkheads are used to hold it open temporarily. The drifts likewise are not usually maintained after being undermined. Figure 26 shows a section of a stope.

In Veins Using Stringer Sets.- As stated previously, a stringer set is one in which a stringer is used as a cap over two or more sets. The ends of the stringers may or may not be blocked to the walls. Where two or more stringers are used in a line they butt end to end. Stringer sets are mostly used in veins that usually are not over 18 feet in width, two or more stringers in a line being required only in locally wide sections. The same general method of mining is followed as when regulation square-sets are used. The practice at the Hecla and Morning mines illustrates this method of mining. The orebodies at these mines are particularly adapted to the system. Large-sized, round timber is also locally available.

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The main lead and zinc orebodies at the Hecla mine occur along almost vertical shear zones in quartzite.[29] They range from 3 to 40 feet in width and are associated with an irregular lamprophyre dike which ranges from 2 to 12 feet in width. The ore may occur on either or both sides of this dike. There is no definite line of demarcation between the lode and country rock. Portions of the wall have a tendency to break to quartz stringers and to gouge accompanying ore stringers, which causes extremely heavy side and top pressures.

It is often necessary to mine a face of ore having a horse of waste between two stringers. This horse of waste may be 6 or 7 feet wide, but the whole face is usually mined; an effort is made to shatter the waste to permit maximum underground sorting. This method is varied by mining one streak for two or three floors, filling tightly, and then mining the streak on the other side of the waste. The use of the latter method is determined by the width and condition of the included waste.

The stopes in the Hecla have a tendency to widen with depth, causing numerous changes in practice to meet new conditions. The early practice of placing a chute, manway, and timber slide on 50-foot centers in stopes in the Hecla orebody was abandoned because of the excessive side weight which caused a large amount of repairing in the raises and manways. With this method only about 70 per cent of the excavation was filled with waste. The chute interval was then changed to 100 feet (see fig. 27).

A raise is first run to the level above. Beginning at the raise, floors are mined in both directions for a distance of 100 feet. Waste for filling is drawn from the central raise. As stated before, the maximum width of the drift generally is held at 18 feet, but if the ore attains a greater width the stope is widened on the first floor to the full width of the ore.

The first floor is mined from the completed raise to the end of the block and timbered as the face advances. The ore is passed through the top lagging of the drift sets into cars on the haulage level. Before blasting, a lagging is removed from the top of each set (or a floor lagging of a set above) and the space covered with short cross boards, which are pried up one at a time as the cars are loaded. The second and third floors are then mined in the same manner. As the third floor is being mined, the timbers for supporting the filling in the stope can be placed. The bottom of the waste corral is on top of the first floor above the drift; the first floor is kept open to allow repairing of the drift or the corral bottom. After the third floor is far enough advanced, the second floor can be filled. Waste is obtained for development work on the level above, from the surface through a rock raise, and from sorting. A track is placed on the third floor for the tramming of waste from the raise.

When the third floor is completed and the fourth floor started, this track on the third floor is used for the transfer of broken ore from the face of the stope on the fourth floor; the ore is dropped from the mining floor into the car on the third floor and thence trammed to the chute. When the fourth floor is advanced from 25 to 35 feet from the raise, filling is started on the third floor; the track for distributing this waste is placed on the fourth floor.

This method, after the first floor of waste fill has been placed, allows practically only one floor to be open at a time. When wall conditions permit, the track for waste fill is placed on every second floor, and two floors are then open from the top of the filling to the back of the stope.

This general method of advance is carried upward in the stope until three or four floors, depending on the ground, of unmined ore remain to the level above. This remaining ore is removed by vertical slicing, starting from the completed raise. As the vertical slice

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[29] - Foreman, Charles H., Mining Methods and Costs at the Hecla and Star Mines, Burke, Idaho: Inf. Circ. 6232, Bureau of Mines, Feb., 1930, 21 pp.

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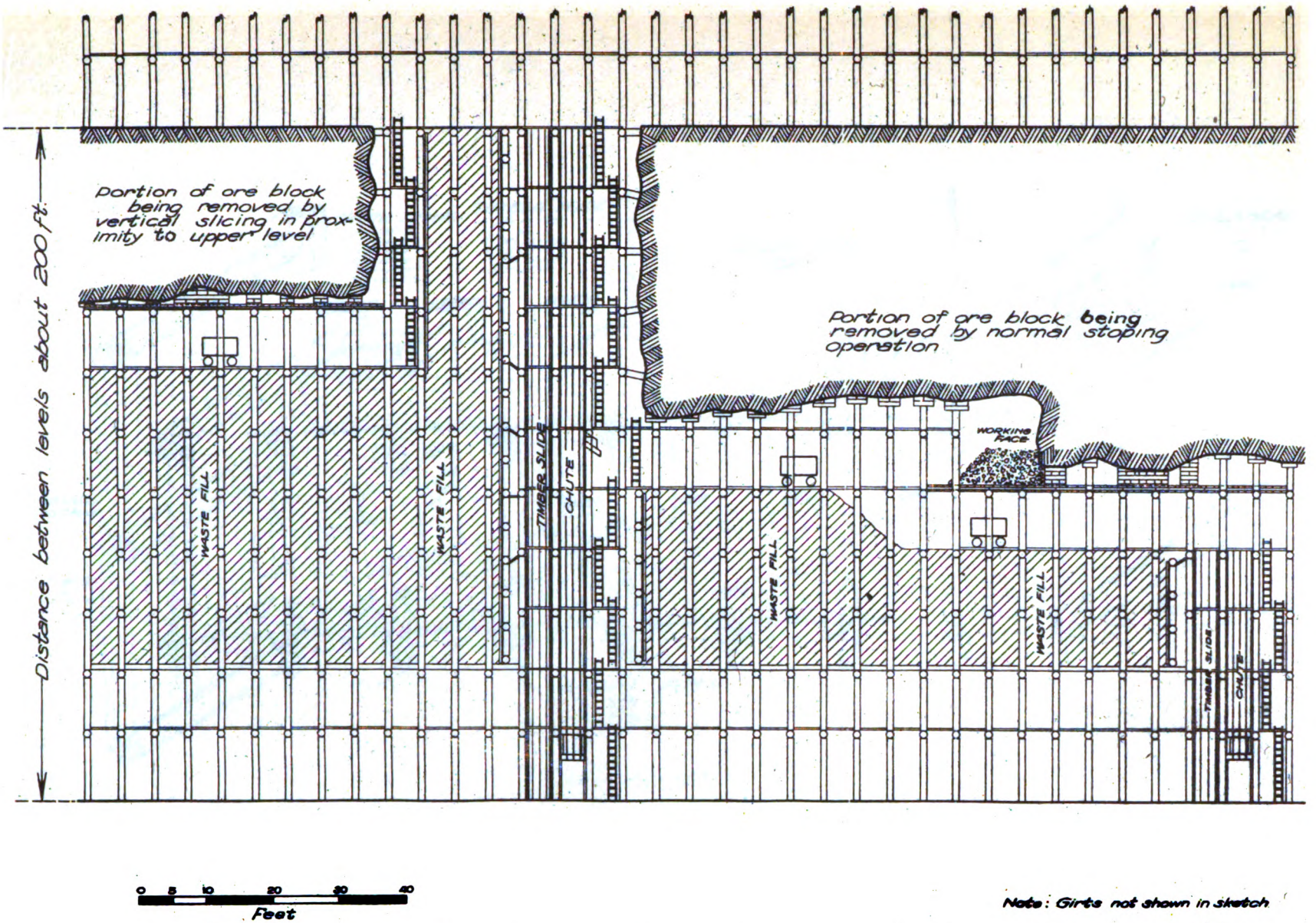

Figure 27.- Stoping method at the Hecla mine

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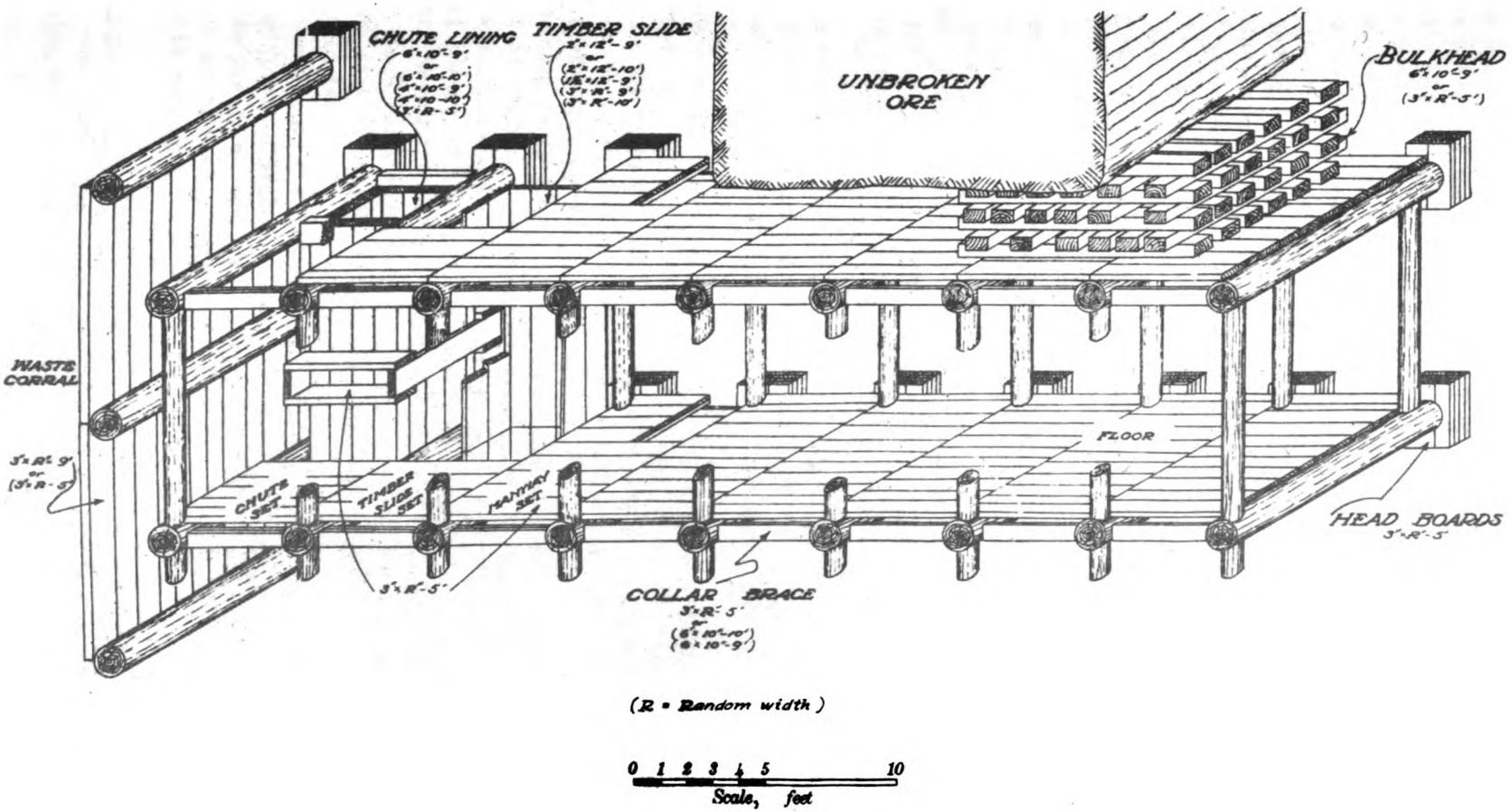

Figure 28.- Stope timbering at the Hecla mine

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of ore is removed, fill is placed to the level above, between the advancing face and the raise. From 5 to 10 feet is kept open between the face of the vertical stope and the waste fill. Stringers are placed on the drift and first floor above to support the drift timbers and the overhead waste gob (fig. 27).

Round timber is used in the stopes and for drift sets. Figure 28 shows the details of timbering in a stope, with the different sizes of timber and lagging used. Larger timbers are used in the drift and on the first floor than in the stope. The distance from the bottom of the drift cap to the rail is 9 feet, to allow for handling 16-foot timbers in the timber slides. As the ground is broken in the stopes and removed, the stull sets are placed from all to wall. Flooring consisting of 3-inch fir lagging is laid on each set as put in. In extremely bad ground the cap of the set may be placed before the complete removal of broken ore from the face, thus giving immediate support to the walls. The broken ore is used as staging for placing the caps.

The caps are of variable lengths and are placed from wall to wall of the stope with the necessary vertical posts and horizontal collar braces. The general procedure is to place these caps at 5-foot intervals, measured horizontally, and at 9-foot intervals, measured vertically. As a 16-foot cap is the maximum length that can be landed in the stopes, it is sometimes necessary to place two, but rarely three, caps end-on-end to span the stope. In all cases about 12 inches of heading boards are placed against each wall at the end of each cap or string of caps. These heading boards are cut from regular mine lagging 3 inches thick and of random width and are placed parallel to the walls. Any excessive side pressure before the fill is placed is first noticed in the compression of these heading boards, before the failure of the cap. This pressure on the cap is relieved by removing the crushed heading boards and any ground necessary, and placing new heading boards against the original cap.

The timber for the waste corral bottom consists of 6 and 8 inch round lagging cut in 10-foot lengths. Waste timber is placed on top of the round lagging to make the bottom tight.

Caps for the waste or gob fence at the raise are placed 30 inches from the center of the outside raise caps, and spaced 5 feet apart, center to center, vertically; they are blocked to the sides of the stope at each end. Five-foot lagging is placed on the stope side of these gob caps to retain the filling. Repairs to either the gob caps or the raise caps can be made without disturbing the other.

This method of mining permits continuous filling and mining and keeps the space between the back and the fill at minimum. It enables a crew to be organized according to the width of a stope, so that a regular schedule of operations may be maintained.

The same general scheme of mining and timbering is used at the Morning mine as at the Hecla; the vein structure and the physical characteristics of the wall rocks are also quite similar. The dip of the Morning vein ranges from 80° to vertical. The productive ore zone is from 1,500 to 2,000 feet in length.[30] The stoping width of the vein varies from 6 to 30 feet, averaging about 13 feet.

The ore is not heavy, and the timbers are not required to bear much vertical weight. The wall rock has a tendency to swell and slab off in large, platy pieces as soon as the air reaches it. This side pressure from the walls necessitates close timbering at all times. Moreover, if there are any places in the vein, such as drifts or raises, to be kept open, continual repair work is necessary.

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[30] - Wethered, C. E., and Coady, Leo J., Mining Methods at the Morning Mine of the Federal Mining and Smelting Co., Mullan, Idaho: Inf. Circ. 6238, Bureau of Mines, Feb., 1930, 13 pp.

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In the original method of mining, ore chutes were spaced 25 feet apart. To eliminate the exceptionally high repair costs of these chutes, due to the heavy ground, the chute interval was changed to 125 feet.

The two methods of stoping are shown in detail in the longitudinal section, Figure 29. In the present method of mining (No. 2, fig. 29) broken ore falls to the mucking floor one set below and is shoveled by hand into a car on the tramming floor, the next set below, through movable steel slides. From here it is hand trammed in 1-ton cars to the chute and dumped.

As soon as the face on the mining floor has advanced 125 feet the rails, tram car, and steel slides previously described are moved up one floor. The rails are relaid, a new mining floor is started, and the cycle of operations is repeated. The tops of all chutes in the stope have grizzlies, made from old rails cut in 4-foot lengths and spaced 10 inches apart, through which the ore is dumped (fig. 19).

A stope set consists of two round posts 8 feet long and one round cap (slabbed on one side) varying in length from 8 to 16 feet (fig. 7, B). The length depends upon the width of the ore at that point. Two girts, ten or twelve strips of 3-inch lagging, blocks, and wedges complete the set. The over-all height of a stope set is 9 feet, and from the center of one cap to the center of the next the distance is 5 feet.

The supplies are hoisted up the timber slide of the raise to the mining floor by a small air hoist. With the aid of additional men the timber is transferred and placed in position. Timbermen working in pairs make the preparations for a set of timbers and block the set in place; several pairs of timbermen may be working in the same stope.

Waste for filling the stopes is obtained by hand sorting in the stopes or by driving waste raises or crosscuts in the walls. The waste raises are driven on about a 45° slope. Waste crosscuts are driven horizontally and at right angles to the strike of the vein. Scrapers are used for removing waste from the waste crosscuts to the stope. Waste filling in the stopes is not leveled off but is allowed to lie at the angle of repose. No waste for filling is transferred from one level to another through the shaft. If waste from development can not be used on the level on which it is made, it is hoisted to the main tunnel and trammed to the surface waste dump.

Ventilation raises are often put through from a stope to the sill above. When such a raise is contemplated, enough unfilled space is left in the stope to take care of the waste made in the raise. The raise is then started from the top of the stope and driven in the footwall to the level above.

The procedure described is continued to about the eighteenth floor and the stope is then filled to the back. The remaining floors are mined in vertical sections from the level above downward.

In Replacement Deposits Using Stringer Sets.- Stringer sets are used in the irregular orebodies at the Silver King Coalition mine.[31] Usually a stope is advanced horizontally lengthwise with the orebody as a continuous face. In large orebodies where the ground is heavy the ore is mined in horizontal sections. The average dip is 20°. The ore is developed by short raises from sublevels driven under the orebody, and sometimes by winzes.

Practically all stoping is by overhand methods. As few holes as possible are drilled and blasted in the ore in order to save powder and to prevent shattering of the walls and the dilution of the ore with waste. In some cases a single hole is all that is required to break many tons of ore.

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[31] - Dailey, M. J., Mining Methods and Costs of the Silver King Coalition Mines Co., Park City, Utah: Inf. Circ. 6371, Bureau of Mines, Nov., 1930, 12 pp.

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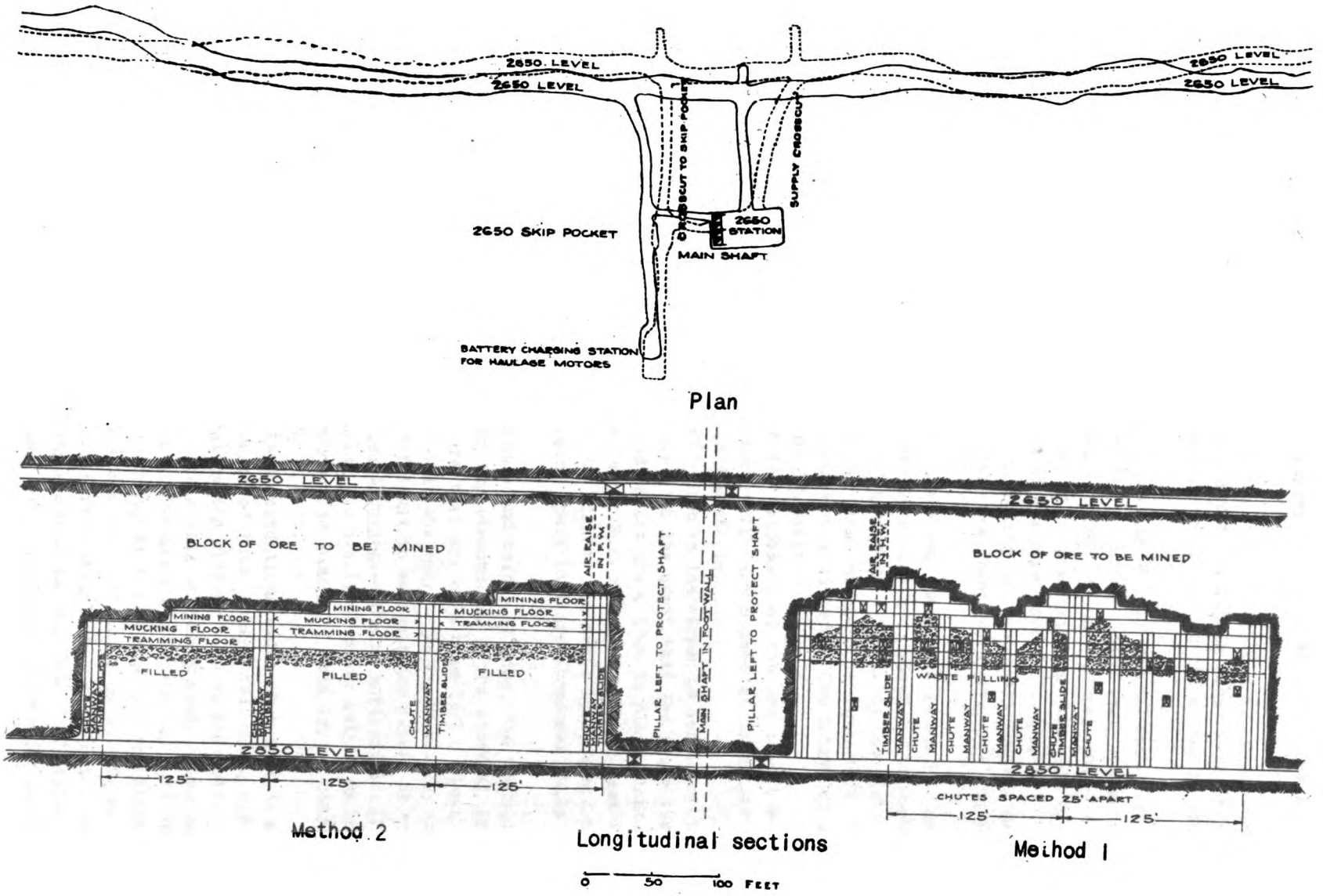

Figure 29.- Plan of two levels and longitudinal sections of typical stopes, Morning mine

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The broken ore is moved down the dip of the stope by hand-shoveling, wheelbarrows, or cars. Some attempts have been made to use scrapers, and also to use a mechanical shovel, but were unsuccessful.

The ore is drawn off through chutes into 1-ton cars and trammed either by hand or motor to the nearest gathering switch. The chutes are made of 2-inch plank with wooden control gates sliding in cleats nailed to the chute sides. The floors of the chutes or storage boxes have a pitch of 55°.

Stringer sets (fig. 7, A) consist of unframed 8 by 8 inch caps 10 feet long, supported on three round posts of 8 to 10 inch diameter and 6 feet 6 inches long. Sometimes 8 by 8 inch square posts are used. Round girts 4 feet 4 inches long are either spiked to the posts and caps or held in position by small blocks nailed to the post under the ends of the girts. Two-inch scabbing is nailed on the bottom side of the caps between the posts.

Portions of the larger stopes are filled with waste to support the hanging wall as stoping advances. In such cases all available timbers are taken out before filling so that they can be used again.

As previously stated, in the part of the mine where the ground is heavier and the timbers are subjected to greater pressure, the stringer sets are framed. The posts and caps consist of 8 by 8 inch and the girts of 4 by 8 inch timbers. In mining the flat, heavy orebodies where it is not practicable to advance the stope as one continuous face, the orebody is mined in sections about 50 feet wide and supported on timbers. The length of such a section depends upon the condition of the overhanging walls.

Around the edges of the orebodies where the thickness of the ore is not so great and less support is required, 8 and 10 inch round stulls are placed at irregular intervals. Headboards of varying dimensions are placed on the stulls.

Between 15 and 20 per cent of the material broken in the stopes is sorted out underground as waste and is returned to the stopes for fill. In the event that the waste thus obtained is not enough to fill a stope, waste drifts and raises are driven in places that have merit as prospects or as ventilation or haulage openings. Such drifts are 5 by 8 feet in section, and are run close to the section of stopes to be filled. To avoid loss of ore that may be scattered in the fill when blasting, all stoping operations are abandoned while filling is being done.

After a section of stope has been mined out, and before filling, the footwall is swept clean. This is done with wire brooms and by experienced men. The footwall is carefully inspected for small bunches or stringers of ore that may have been left. These often lead to finding profitable bunches of ore extending into the walls. So thoroughly is the cleaning done that after a stope has been swept it is difficult to see what the nature of the ore was.

Square-setting with Top-slicing and Sublevel Caving.- Mining horizontal slices of ore from the top downward by square-sets and letting the overlying waste settle is the practice followed at a few places. The posts may or may not be blasted. This is, of course, a modification of the top-slicing method.

At the Black Rock mine, where abnormal local conditions exist that make it impractical to hold intermediate workings open for any length of time, ground that would ordinarily be mined by downward vertical slices is taken out by top slicing with square-sets. The slices are taken off one to three floors in height, depending on the ground. When more than a floor is to be taken, a drift is run to the end of the ore block on the footwall of the lower floor and timbered with square-sets. Then, starting at the end of the ore block the floor above is mined back to the raise chute. If there are two floors of ore above the intermediate sill the two floors are mined together in retreating. Either standard sets or "cap sets" such as are employed for underhand stoping are used in this method of mining, depending on the height desired. When all the ore on and above the intermediate sill has been worked

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out a new slice is started below from the raise and worked in the same manner. No filling is used, and although the posts are not blasted out, the upper workings soon close in and fill themselves. The temporary flooring used in each slice is recovered before the slice is abandoned.

At the Ruth mine, Ely, Nev., square-setting is employed in conjunction with sublevel caving. This method is used in the high-grade orebody lying mainly between the sixth and seventh levels. The orebody is lens-shaped, has a length of 950 feet, an average thickness of 60 feet, and an average width of 200 feet. In former years the orebody was mined by square-setting and filling. Sections three sets wide and the width of the orebody were carried upwards from a drift driven under the orebody along its length; the drift was timbered with drift sets. The sections were silled out at the top of the drift. Three-compartment combination chutes and manways were carried up in each section at right angles to the drift. The two outside compartments were used for ore chutes and the middle compartment, the one over the drift, for a manway and supply raise. Raises were timbered with standard square-sets (fig. 4, B). A raise was run to the level above in the first section for ventilation and for bringing in filling. The broken ore was drawn to the chutes by a scraper in the center row of sets. An effort was made to keep two floors 15 feet 4 inches, center to center, open at a time so that plank slides could be used in the two outside rows of sets of the lower floor to guide the ore as mined on the floor above to the scraper runway. The sides of the sets adjacent to the unmined ore were lagged with 2 by 12 inch plank. The waste was distributed laterally by the scrapers.

Difficulty was encountered in keeping the stope sections open for three sets wide and two sets high, owing to the heavy ground, and the waste required for filling could not be conveniently obtained. Another objection to the system was the large amount of timbering required. To overcome these disadvantages the square-set method was abandoned in favor of a sublevel-caving method, which has proved more satisfactory.

In preparation for mining by sublevel caving a drift is run under the length of the orebody as in the square-set method. Three-compartment raises are driven on 17-foot centers from the drift to the top of the orebody. These raises are at right angles to the haulage drift, and the center compartment, used as a manway and for supplies, is directly over it. Raises are timbered with 10 by 10 inch square-sets. Dimensions of the square-sets are 5 feet 6 inches by 5 feet 8 inches, and 7 feet 8 inches high, measured center to center.

Grizzlies of 6 by 10 inch timbers with 12-inch openings are used on the top of the ore chutes. At the tops of the raises, crosscuts timbered with 10 by 10 inch square-sets are extended to the lateral limits of the ore directly beneath the capping. Mortised sills, 6 by 10 inches, are used under the posts to prevent the bottoms of the posts from being forced out of alignment.

The 11-foot 4-inch pillar of ore between consecutive crosscuts is mined by starting at the ends of the drifts and retreating toward the chutes. Square-sets of 8 by 8 inch timbers are placed as the pillar is mined. Scrapers operating on a floor of 2 by 12 inch plank laid on the sills are used in driving the crosscuts and mining the pillars. Cross-scraping is employed to drag the ore from the pillars into the crosscut runways.

Old timbers and sawmill trimmings are used to form a mat beneath the capping, thus preventing dilution when the ore below is extracted. The square-set posts in each slice are broken with small charges of dynamite placed in auger holes.

In taking slices of ore after the first, instead of driving the drifts directly beneath the mat they are run about 16 feet below, leaving about an 8-foot pillar over the drift square-sets, as shown in the cross section (fig. 30). Mining progresses as in the first slice, but in addition the 8-foot pillar over the back of the sets is also taken. No timber is used in mining the second floor. Timber slides are used to guide the ore from the second floor into the drift runways.

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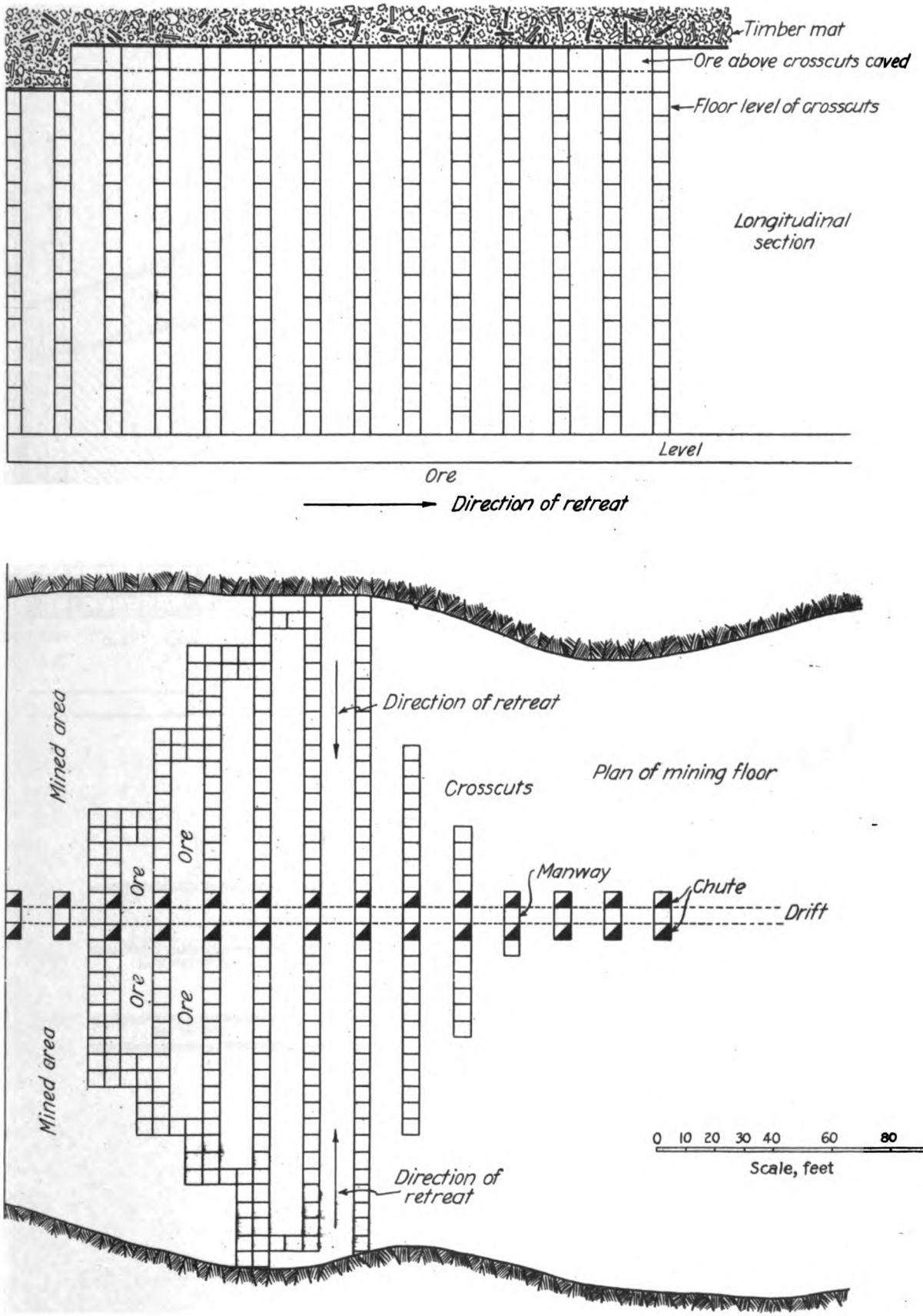

Figure 30.- Method of sublevel caving at the Ruth mine

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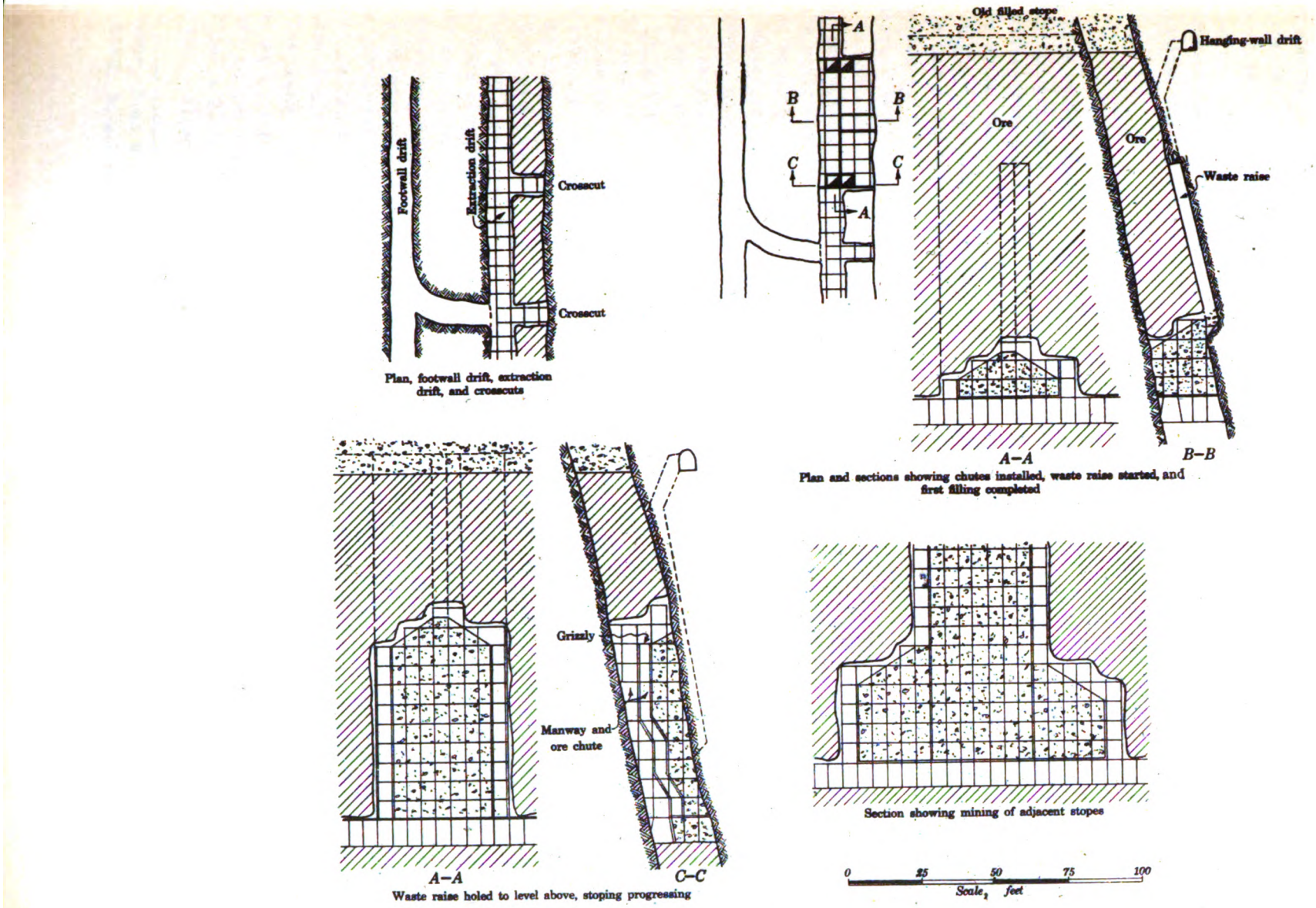

Figure 31.- Timbered rill method at the Magma mine

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In this method of mining, the area remaining open at a time is small; the amount of timber required is cut in half in comparison with square-set method; mining is rapid, as a number of places can be worked on the same floor without interference; waste fill is unnecessary; and hand shoveling is practically eliminated. The procedure in mining with the sub-level-caving system at the Ruth mine is more systematic, as the general scheme does not have to be varied, like the square-set method, to suit local conditions arising from heavy ground and the necessity of obtaining waste for filling. If the ground becomes heavy, the sets can be blasted down as soon as the ore is mined and the mat and capping allowed to settle over the unmined ore.

Rilled Sections

In a rilled system of mining an advantage is gained in that less shoveling is necessary than with horizontal sections. The main operating disadvantages are the difficulty of sorting waste from the ore and the fact that the drillers have to work on an inclined floor. Coarse waste can be sorted out at the tops of the chutes, but small piles of fine material that might be sorted out with shovels on a flat floor must be run with the ore. The rill system has a further disadvantage in very heavy ground in that it is more difficult for the timbermen to catch up bad places, and a cave is likely to be more serious there than where horizontal sections are mined.

In many instances where the ore is taken out in inclined square-set sections, the stopes have been started as ordinary rills. Additional support has been needed, which was supplied by the square-sets. Where the ground conditions later improve, the stopes are readily converted back to the original class.

Geological conditions in some cases may be favorable for mining by inclined rather than horizontal slices. In other instances the contrary may be the case. Because of the direction of parallel planes of weakness blocks of ore may fall more readily with one method of mining than with the other.

In Narrow Veins.- At the Magma mine veins under 15 feet wide are mined by the timbered-rill system.[32] The ore occurs in veins and usually extends a considerable distance both on the strike and dip. The walls of the veins at most places in the mine require immediate support when the ore is taken out. Timbered stopes soon start to take weight and all stopes must be filled.

In developing a block of ground for the timbered-rill stoping system, crosscuts are run through the vein from the footwall drift at intervals of approximately 150 feet (fig. 31). From these crosscuts an extraction drift is driven in ore along the footwall of the vein. Stopes are silled out from this drift and timbered with square-sets. The details of the sets are given in Table 2. Sill floor posts are 8 feet 3 inches long, and regular posts are 6 feet long overall. Battered posts are used in the row of sets next the footwall (fig. 8, E), which row later forms the extraction drift when the stope is filled. The outside of the extraction drift is lagged to prevent the fill from running into it. Pony sets over the extraction drifts are also kept open on account of the loading platforms.

The length of each stope along the vein depends upon the width of the vein and the character of the ore. Generally a 30 to 40 foot stope is started and the back inclined from the top of the sill set at each end to four or five sets in height at the center. From the top floor a 2-compartment cribbed raise for waste filling is driven in the hanging wall next the vein. After this raise reaches the level above, it is also used for lowering timber

[32] - Snow, Fred W., Mining Methods and Costs at the Magma Mine, Superior, Ariz.: Inf. Circ. 6168, Bureau of Mines, Sept., 1929, 32 pp.

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and supplies ito the stope. The waste rock from the raise is also used for stope filling. At each end of the stope two adjoining square-sets are lined with 2-inch lagging and used for extraction raises as the stope is mined upward. Occasional offsets keep these raises next the footwall. They are oriented with their long dimension across the vein if the latter is two sets or more wide; otherwise, parallel to it. One compartment is used for a manway and the other for an ore chute. The top of the ore chute is protected by grizzlies made of square-set caps spaced 9 inches apart. After each filling of the stope a new grizzly is built over the top of the chute, the timber from the old one being salvaged for use in the stope. Filling is stopped before the waste covers the tops of the square-sets so that succeeding sets can be placed without digging. The angle of slope of the fill is the angle of repose, or roughly two sets horizontally to one vertically. After filling, a floor of 2 by 10 inch by 5-foot lagging is laid on the waste; cross pieces of lagging are used for sills or nailing strips.

A 7-foot cut is now taken from the back, starting at the ends over the extraction raises and working up toward the center. Square-sets are stood as soon as room is made. The broken ore slides down the floor and into the extraction chutes. Little shoveling is necessary. Some breaking with hammers is required to pass the large pieces through the grizzlies. Usually three such cuts are taken before the stope is again filled.

Succeeding stopes are generally 15 to 25 feet long. The stopes are silled out as before, and the back is given a downward slope away from the filled stope corresponding to the angle of repose of the waste. This opening, as before, is timbered with square-sets. Waste is then run into the stope through the extraction raise of the previous stope, after which a floor is laid. The stope is mined to the level above by alternately taking two or three 7-foot cuts of ore and then filling. A raise consisting of two square-sets is taken up on the far end of the stope for an ore chute and a manway.

A series of stopes may be worked at one time. Occasionally waste filling may be run from one stope into the next.

A variation of this method is used where the ground will stand sufficiently well. The vein is silled out as before, but for a length of ten sets and a height of two sets above the sill. This space is timbered, and the back is pyramided up to a height of about eight sets in the center, from which point a waste raise is run to the level above. Just enough ore is mined by this first operation for the waste from running the raise to fill the space. Mining now proceeds as before until the ends of the stope are about eight sets high. Then "wing" stopes are started at each end, four sets long, and mined up eight sets. Filling for the wings is run in over the filling of the center stope. In this way a length of 18 sets or 90 feet along the vein is mined and filled with only one waste raise. When the center of the stope reaches the level above, and the filling will no longer run by gravity to the ends of the stope, short raises are put up to the level above near the ends of the stope. When using this method, pillars of ore 15 feet long are left between adjoining 90-foot stopes to prevent possible subsidence of the hanging wall and injury to the hanging-wall drift. The pillar is afterward recovered by a slicing method.

In Wide Veins.- At the Anaconda Copper Co. mines, at Butte, timbered rill stopes have been used successfully in veins of such a width (over 10 feet) that open-rill stoping was difficult and dangerous.[33] The ground mined by the timbered rill is intermediate between that stoped by the open rill and by horizontal sections.

The preliminary development necessary for timbered-rill stopes is about the same as for open rilling. Levels are 200 feet apart vertically on the vein. The drifts are offset into

[33] - Bicknell, H. L., Advantages of Using Timbered Rill Stopes: Compressed Air Mag., Aug., 1921, pp. 10183-10189.

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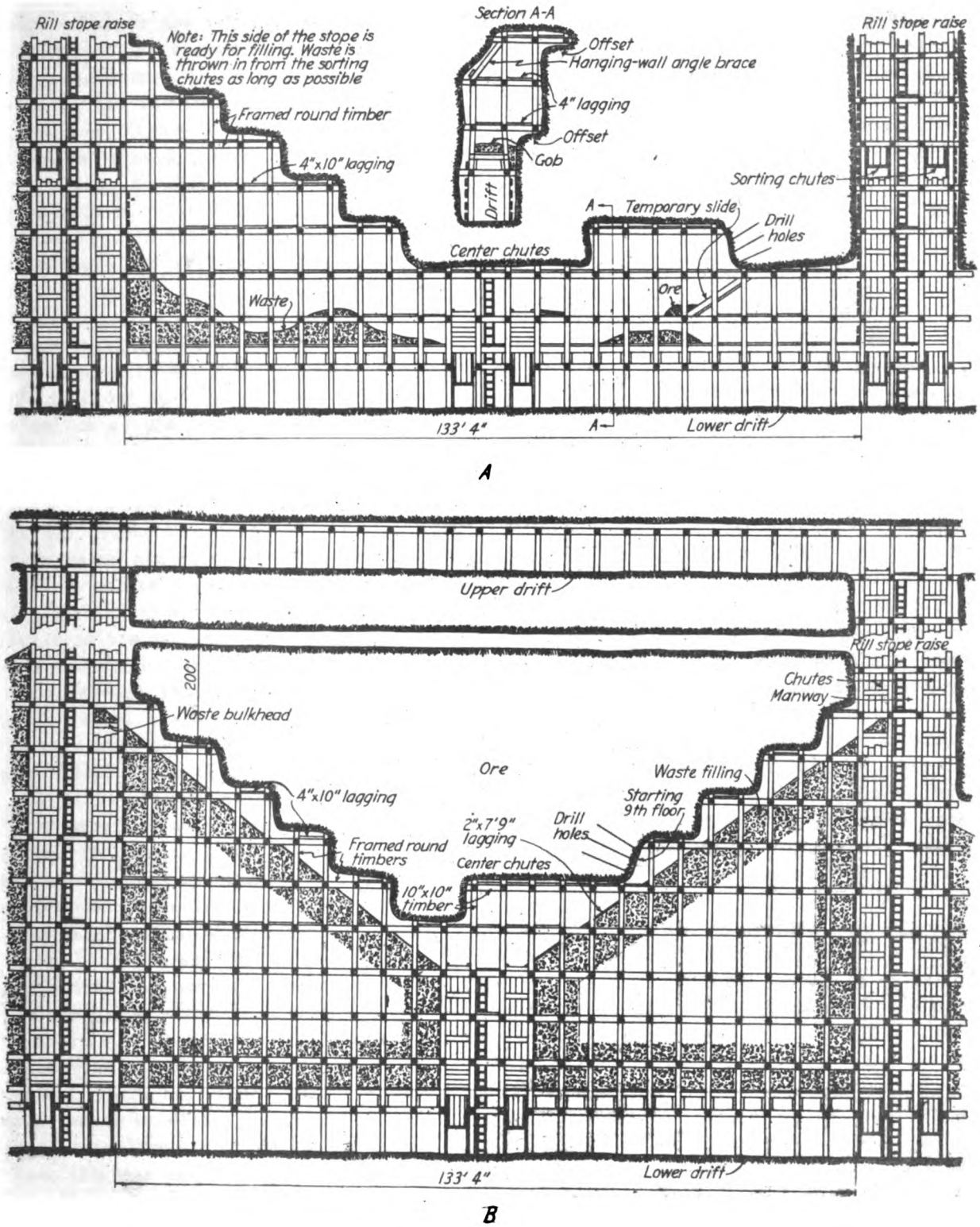

Figure 32.- Timbered rill stope at Butte: A, Early stage of stoping; B, stope completely developed

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the hanging wall at every 11th set for raises; the 12th, 13th, and 14th sets are made two sets wide. Raises are started in alternate offsets, beginning at the first, as soon as the drift is driven far enough ahead that the two operations do not conflict. After the raises have progressed upward for five or six floors the first floor over the drift between the first two raises is mined out. The second floor is then mined out two sets wide, as shown in section A-A, Figure 32, A. After the first and second floors are mined the sheeting timber is put in to hold the waste filling and the center chute is built. The stope is developed for rilling, as shown in Figure 32, A. The ore is carried down to the second floor by temporary slides. The waste is sorted out and thrown into the gob. The ore is then taken in wheelbarrows to the chute. When the raises have been completed a bulkhead is built in the waste chute and filling is run into the stope just above the caps of the seventh floor. The angle of repose of the filling will leave one or two sets open on each floor. All lagging is removed from the floors before running in the filling. Beginning over the chutes, a cut of ore is taken out to the raise. The ore is blasted down on floors placed on the fill. One side is usually being filled while the cut is being taken on the other. A fully developed stope is shown in Figure 32, B. At this stage of stoping, waste is sorted out of the ore at the bottom of the incline and thrown into one of the two center chutes.

In places where the vein is narrow and the walls fairly firm, an open-rill system may be used, while in the wider portions of the vein timbering would be required. Occasionally one side of a stope would be mined as an open rill and the other side by a timbered rill.

At the Ground Hog mine, Vanadium, N. Mex.,[34] the inclined cut-and-fill method is used in narrow veins and filled square-setting in wide veins. Formerly horizontal filled stopes were used in narrow veins. The raises served as fill raises above the stope and as ore chutes below. Trouble was experienced because of caving of the ore and wall rock. Horizontal slips entering from the hanging wall cut the ore at about 6-foot intervals. Often, when a slice was finished and ready for the fill, the ore would cave to the next slip above, bringing down much hanging-wall waste with it. This made stoping dangerous, especially for the shoveler who had to wheel the ore through the stope to the chute.

To eliminate this danger and to be able to fill closer to the back, this method of stoping was abandoned in favor of rill stoping. With the rill system it has been possible to hold the slabs of ore better. In a single cut up the incline more slips are exposed, but each for only a short distance. In addition, while a shoveling platform offers the same facilities for sorting as a flat-backed stope, the shoveler works in only one place, where he can be protected by timbers if necessary. The ore runs by gravity toward the chute, and the fill spreads itself almost entirely without assistance.

The main ore shoot occurs as irregularly shaped connected lenses ranging from 3 to 25 feet wide. The average dip is about 50°. The ore and wall rocks are fractured and must be watched closely to prevent disastrous caves. The ore consists of heavy sulphides of lead, zinc, copper, and silver, which has little strength and in general requires more support than the walls. It will stand if not opened over too great distances; if too large an area is unsupported it breaks into large slabs or blocks. The footwall consists usually of a thick gouge, which may cause trouble by sloughing, thus weakening the back and increasing the amount of waste handled. Frequently the vein material next to the footwall consists of a low-grade siliceous ore which can be left in place, forming a strong and satisfactory wall.

When the vein is narrow, rilled cut-and-fill stoping is employed, which requires little timber. Where the vein is wide, square-sets and filling are used.

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[34] - Richard, F. W., Mining Methods and Costs at the Ground Hog Unit, Asarco Mining Co., Vanadium, N. Mex.: Inf. Circ. 6377, Bureau of Mines, Nov., 1930, 13 pp.

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Development in the ore consists of drifting on the main levels and sublevels. The sublevels are untimbered, except in a very few places. They are never used for starting stoping perations, but have been found very convenient in distributing filling. Their chief advantage, however, is that they shorten the length of raises used for ore and waste passes to about 65 feet instead of 135 to 140 feet. These raises are 5 by 7 feet in section, spaced at 50-foot intervals along the vein, and are timbered with stulls. They also help to drain and ventilate the blocks.

In the square-set-and-fill method a stope section is 100 feet in length and the full width of the vein. The ore is silled the full width of the vein. Sills of 10 by 10 inch timbers are placed from wall to wall at 5-foot intervals. Double 2-inch flooring is laid on these sills. All square-sets are 5 feet square and 7 feet high and consist of 8 by 8 inch posts and caps and 6 by 8 inch girts. After the sill floor has been timbered the full width and length of a 100-foot section, the first floor is mined out and timbered with square-sets. The sill floor is then filled with waste except for the haulage way, which is lagged with 2-inch plank to hold the waste fill. The raises are now enlarged and timbered to the next main level with square-sets one set wide from wall to wall.

Starting at the center raise of a 100-foot block on the second floor above the sill floor, three lines of sets are taken out on both sides of the raise and from wall to wall. On the third floor two lines are taken out in a similar manner, and on the fourth floor one line is removed on both sides of the raise. This forms a pyramid of open ground with the raise at its center. Waste is next run in through the raise and the open ground is filled as close to the ore as possible; a floor is then laid on the fill. Stoping is now continued on either side of the raise as desired, until the toe of the rill is within 10 feet of the next chute, after which the last two sets are carried flat to furnish a shoveling platform where sorting can be done.

Combination Rill and Horizontal Sections

In wide veins sections which are advanced either horizontally or vertically may be stoped by a rill method. At the Park Utah mine a combination rill and horizontal slice method is used.[35] The waste is run in to the angle of repose and the ore is drawn horizontally by scrapers to chutes.

The lead-silver ore at this mine occurs in sedimentary rock, principally in fissures ranging in width from 3 to 80 feet and varying in dip from 40 to 55°. The maximum length of a single ore shoot is 900 feet. The walls of the veins are usually weak and will slough readily if left unsupported. Faults cutting the veins at acute angles are also a source of trouble, as they form large wedge-shaped masses of rock, which if not adequately supported will cave into the stopes and dilute the ore, or possibly cause loss of the stope.

The square-set-and-fill method is used in all stopes over 12 feet wide, and in 1930 it produced nearly all the ore at this mine. The system of mining was planned primarily to permit the waste filling to flow to its destination by gravity, and to allow handling the ore with scrapers. In preparation for stoping, a drift usually is run on the footwall; in wide veins a second drift is run in the footwall parallel to the strike (fig. 33, A). A drift is also run in the hanging wall on the level above for bringing filling into the stope. Raises are run on 100-foot centers to connect with the hanging-wall drift. The first raise is run before stoping begins; subsequent ones are put up from the stopes as needed.

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[35] – Hewitt, E. A., Mining Methods and Costs at the Park Utah Mine, Park City, Utah: Inf. Circ. 6290, Bureau of Mines, June, 1930, 18 pp.

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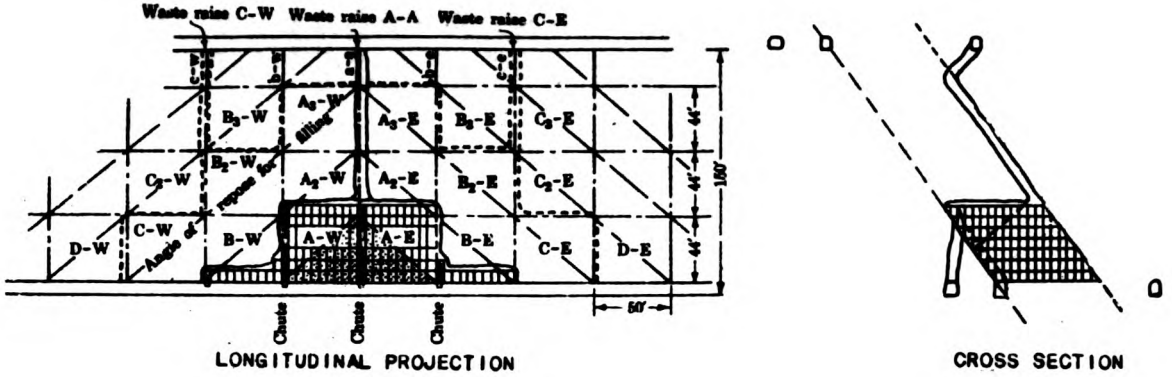
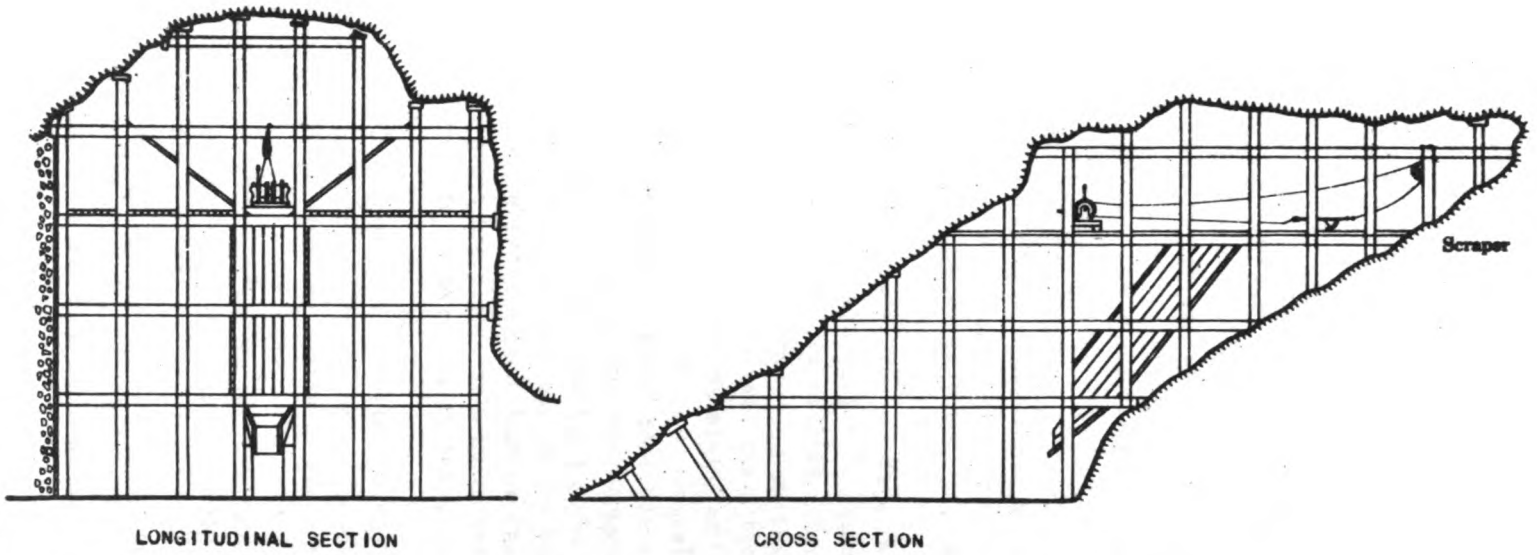


A. Stope panel layout



B. Use of scraper in a flat square-set stope

Figure 33.- Square-set stoping at the Park Utah mine

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Chutes for ore passes and manways are carried up at intervals of 50 feet, or at every tenth set along the length of the ore shoot. They are lagged off from the fill with 2 by 6 inch plank. As the stope advances upward the ground becomes heavy so that the square-set chutes and the drifts in ore are difficult and costly to maintain. To avoid the cost of maintaining these chutes and drifts, raises are put up from the drift in the footwall on 50-foot centers (fig. 33, A), and the chutes on the sill floor in the square-sets are abandoned.

The raises on the 100-foot centers are the apices of the rills. The ore is silled out from the top of the footwall drift. Sections are mined out across the width of the veins from footwall to hanging wall.

The first section of a stope is 100 feet, or 20 sets, in length, 6 sets high, and is the full width of the vein, which may be from 12 to 80 feet. Successive sections started after the first and adjacent to it are 50 feet, or 10 sets, in length and 6 sets high. When the 100-foot section, represented in Figure 33, A, by blocks A-W and A-E, has been mined 6 sets high, stoping is started simultaneously in blocks B-W, B-E, A2-W, and A2-E by horizontal slices one set high. The slices in blocks on the sides are started at the square-sets and in blocks above from the central waste raise A-A. The length and height of the sections are determined by the angle of repose of the waste material used for filling, which is about 40°. The inclined lines shown in the sketch represent the angle of repose of the waste filling at various stages of mining. As the stope advances to the positions shown by the dotted outlines (fig. 33, A), additional waste raises C-W and C-E are driven.

The floor pillar 10 feet thick, which is left under the level above as the stope is carried upward, is mined out in a separate operation by vertical slices across the width of the vein. Previous to mining the floor pillar the stope below is filled to within one set of the back between waste raises C-E and C-W.

Horizontal rounds drilled with Leyner machines are used wherever possible in the square-set stopes. The comparatively even back that is left after blasting with horizontal holes facilitates blocking of the sets, and there is minimum danger from falling ground.

Horses of waste in the ore are drilled, blasted, and allowed to drop into the stope fill. Waste filling derived largely from development work is run into the stopes from time to time as the square-set sections are being carried upwards, so that mining and filling are continuous operations. The part of the stope under the hanging wall, where weight is more likely to develop, is promptly filled as soon as a section is mined (see cross section of stope, fig. 33, A). The ore away from the hanging wall has sufficient strength to stand supported by square-sets until filled. Details of the square-sets used are given in Table 2. A maximum bearing area is obtained at the ends of the caps, as these are in the line of greatest pressure, which is from the walls. Square-set timbers are laid down at the mine, completely framed, at a cost of $32 per M. The sill posts are placed on 6 by 10 inch sills set at right angles to the strike of the vein and are held in position on the sills by 2-inch scabbing.

Ore broken in the square-set stopes is run through 8-inch grizzlies before being drawn into cars. The grizzlies are made of 60-pound rails placed across the square-sets directly over the chutes. The rails are blocked into position with the bottom of the rail upward to prevent bowlders from wedging in the grizzly.

The only hand shoveling done in square-set stoping operations is in cleaning down the footwall of the stope preparatory to filling with waste and in the final leveling off of the waste after a section has been carried up to the floor pillar.

The adaption of scrapers to square-set stoping at the Park Utah mine is shown in Figure 33, B. The hoist is mounted on a truck and is moved parallel with the walls of the stope over a floor of 3-inch plank. The scraper is dragged in any line of sets from the footwall

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to the hanging wall of the stope. Plank wings are built between the square-set timbers, which direct the ore to the chutes or to the scraper runway as it is broken. The wings are temporary sloping floors laid over the caps. In other cases the broken ore is allowed to pile up on the footwall until the angle of repose of the ore is such that the ore runs into a scraping line served by a chute. In this case when it is necessary to raise the scraping floor the piled ore on the footwall is dragged into a scraping line by using extra blocks and scraping the ore twice. By leaving out interfering girts along the footwall, several floors may be worked from one position of the scraper hoist. In one instance, in soft ore between good walls, ten floors were mined without changing the scraper floor. This height depends on the condition of the walls and the distance the ore may fall without breaking the square-set timbers. A line of 3-inch plank nailed to the underside of the caps for spragging the hoist enables the operator to change the hoist set-up in 20 minutes or less.

Combination Rill and Vertical Sections

At the Bawdwin mine in Upper Burma the ore is mined in vertical slices or sections. Each section is taken up as a rilled square-set stope.[36] The sections are varied in length and width to meet any condition that might arise. They are taken out along the strike of the vein.

Top-slicing or caving methods could not be used, as the upper levels had to be left undisturbed until the company was ready to mine the overlying low-grade ore. The ore is so heavy and friable that it must be closely timbered to support any opening, and the orebody is so wide that it must be mined in sections.

It was considered that mining with a flat back was too costly at this mine. Stopes are carried up in sections 50 feet long; they are four sets wide in the best ground. As the ground becomes heavier the section is narrowed to three sets, and in exceedingly bad ground, to two sets.

In developing a stope for mining, drifts are driven in the hard footwall parallel to the ore. At every 100 feet crosscuts are driven to and through the ore to the hanging wall. Raises from these crosscuts are put up from level to level and thence to the surface so that waste may be taken directly into the stopes.

In commencing stoping operations auxiliary crosscuts are run across the orebody midway between first ones. A vertical pillar 12 feet wide which is mined after the adjoining stopes are finished is left over the auxiliary crosscuts. Previously when no pillar was left the part of the stope around the chute became very heavy and with difficulty was prevented from caving. Individual ore chutes are carried up for each stope, while previously one chute sufficed for both stopes. The rill stopes have their apices at the main raises and slope down to the ore chutes over the crosscuts. Sets are 5 1/2 feet square by 7 feet 4 inches high to give the proper rill effect.

Manways are on the hanging-wall side of chutes; this gives access to either stope from the manway or the chute. Waste filling is obtained by quarrying or mill holing around the tops of the raises that come to the surface.

Where the vein is wide, a longitudinal section is first taken along the hanging wall, and when this is completed, a second and third section alongside is taken, retreating toward the footwall. Under this arrangement the crosscuts and drifts are never in the bad ground under worked-out stopes but rather in the solid ore or country rock. The part of the crosscut under the completed stope is filled.

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[36] – Calhoun, A. B., Mining Methods at the Bawdwin Mine: Trans. Am. Inst. Min. and Met. Eng., vol. 69, 1923, p. 208.

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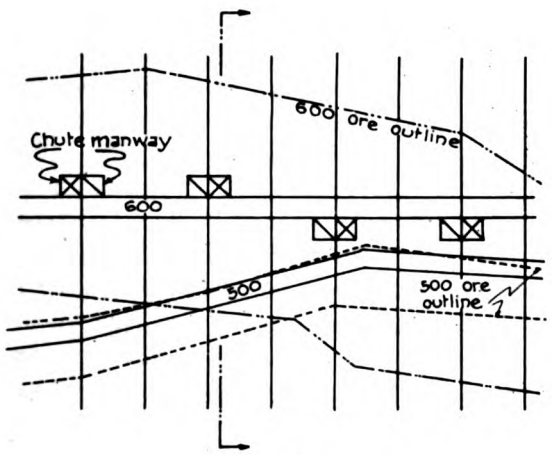
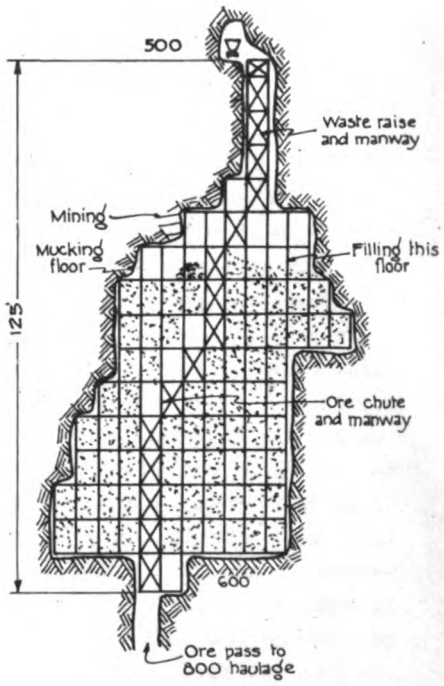
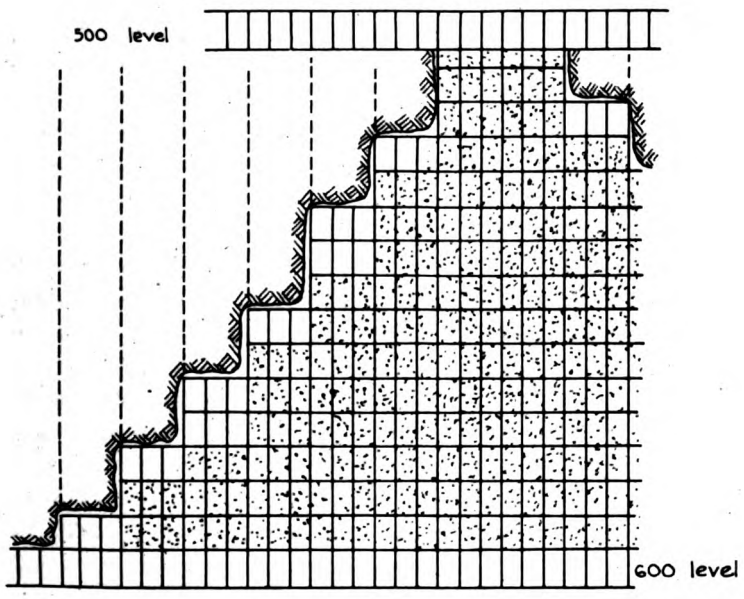


A. PLAN



B. END ELEVATION



C. SIDE ELEVATION

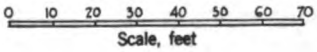


Figure 34.—Square-set stoping at Cananea

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Vertical Upward Sections

As stated before, vertical sections generally are used where the top weight of the ore is greater than the side pressure from the walls. Vertical sections are used successfully in wide veins and replacement deposits with dips ranging from flat to vertical. In narrow veins mining by upward vertical sections would be in effect the same as raising.

The mining of a wide vein deposit with a steep dip by vertical sections is illustrated by the square-set practice at the mine of the Cananea Consolidated Copper Co., at Cananea, Sonora, Mexico.[37] The longitudinal section of a stope shows a rilled effect. The ground is heavy and requires immediate support.

The square-set stopes lie between the 500 and 600 levels, extending over a length of about 200 feet. The vein averages 60 feet wide on the 600 level and 20 feet on the 500 level. A drift was run in the center of the vein on the 600 level and timbered with sill-floor square-sets. From it 2-compartment, 6-post raises were driven to the 500 level at intervals of 30 feet along the vein (fig. 34, A). These raises are on the dividing line between 15-foot stope sections and are offset as they go up to keep them as nearly as possible in the center of the ore. One compartment is a manway and the other a chute. The raise serves for entrance for men, lowering timber and tools into the stopes, dropping waste fill, and extracting the ore. Each raise serves two sections. Eleven feet above the floor of the 600 level a 15-foot section is mined across the orebody, in both directions from the raise, and is timbered with standard 10 by 10 inch square-sets (fig. 2, A). Posts are stood on the solid and the floor is fitted around them. The floor consists of a single layer of 2 by 10 or 2 by 12 inch plank 10 feet long, laid on sills of doubled 2 by 10 inch plank. The sill is not taken out because to do so would make the maintaining of the drift difficult. Eleven feet, the usual height of a top-slice floor, is left because top-slicing is to be used to remove the sill after square-setting is finished. The ground over the drift and up to the stope floor is taken out and a 10 by 10 inch bridge cap put in. A 10-inch block is used between the drift cap and the bridge.

The next floor is mined by starting at the raise and blasting the ore down onto the first floor, from whence it is shoveled into the chute. The sides of the stope are lagged inside the posts with 2 by 10 inch plank, and the posts are laced top and bottom from one side of the stope to the other with wire rope. This rope is obtained by unstranding discarded hoisting cable; it is made up on the surface into 40-foot lengths and coiled for convenient handling. This lacing is necessary to prevent the weight of the fill from breaking out the gob fence when the adjacent section is brought up. Fill is now run in from the level above and a temporary floor laid over it. Mining and filling are now carried on together, mining on one side of the raise and filling on the other, thus speeding the work and leaving as little ground open as possible—never more than two floors. Where the vein is wide a second extraction chute may be made by lagging-off sets before filling. Adjacent sections are started and kept within two or three floors of the preceding one, as shown in Figure 34, C. This order is strictly maintained to prevent the formation of high vertical brows. For the same reason lead sets are always taken on the side next the gob; often three or four sets are carried in advance of the stope to break the corner of the brow before it falls of its own weight and crushes the floor below. Very careful blocking is necessary. Wheelbarrows are generally used for spreading the fill and moving the ore to the chutes, although scrapers are satisfactory and are being used whenever available.

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[37] – Catron, William, Mining Methods, Practices, and Costs of the Cananea Consolidated Copper Co., Sonora, Mexico: Inf. Circ. 6247, Bureau of Mines, Feb., 1930, 41 pp.

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Square-setting at the Old Dominion mine is quite similar to the practice at Cananea.[38] About 21 per cent of the ore at the Old Dominion mine is recovered by square-set methods. The ore occurs in a fissure vein 2 to 60 feet wide. The average dip is about 60°, but ranges from 45° to vertical.

Whenever the walls and vein material stand well and the dip is 75° or more, a shrinkage method is used. Where the ore is of high grade and clean mining is necessary but the back requires support, top-slicing is the method chosen. If the dip is 60° or more and the ore is so low grade that it can not be profitably extracted by selective mining, caving is used. Square-setting is used only where ore is of high grade and the overlying country must be supported. Open stopes are run on small veins where the walls are good and the dip is too flat for shrinking.

The standard square-set practice is to run 15-foot sections across the width of the vein. The opening of more ground than this at one time is unsafe in nearly all the square-set areas.

In prospecting ground that is to be mined by the square-set method, raises are run on the footwall at intervals that are multiples of 30 feet so that they will fit into a stoping scheme that allows one raise for every two 15-foot sections. The raises have two square compartments each 3 feet 4 inches in the clear; one is used as a manway and the other for an ore chute. One compartment of the raise is kept in each section, and the manway is in the section to be taken out last. Waste is brought into the stope through the compartment used for ore.

The broken ore is generally shoveled or wheeled into the chutes. Sometimes in wide stopes slides are used or another chute may be carried up toward the hanging wall by keeping a set open and lined off.

Waste filling is obtained from development work or waste raises. Slides are used for deflecting the waste toward the hanging wall. A part of the waste is placed by means of wheelbarrows or by hand shoveling. The wheelbarrows are filled through a temporary chute built in the square-sets of the floor above. Usually not over two floors are taken out before filling. In most cases filling is done from the footwall side. This requires that the footwall side be kept two or more sets higher than the hanging-wall side. Where the stope is over eight sets wide, a raise may be run into the hanging wall for filling on the hanging-wall side of the stope.

Posts and caps 8 by 8 inches in size and girts 5 by 8 inches are used for square-sets except in excessively heavy ground, where 10 by 10 inch timber is used. The caps are placed parallel to the line of advance of the stope, or at right angles to the strike of the vein. As this permits the set to be lagged from cap to cap and headboards to be placed over the girt to protect the miners while advancing, the necessity of a bridge is eliminated. Wherever spiling ground is encountered this order is reversed so that the spiling may be driven over the cap.

A successful method of mining a wide flat vein by vertical sections has been developed at the Bunker Hill and Sullivan mine, at Kellogg, Idaho.[39] The ore on the hanging wall is mined at the peak of the stope with a nearly vertical working face of ore. This is an improvement on the older method of mining with a flat back, by which unavoidable falls of ore and waste occurred. The orebodies occur in quartzite, ranging from 30 to 125 feet in width and from 300 to 1,000 feet in length. Stoping has been continuous for 5,000 feet on the dip.

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[38] – Shoemaker, A. H., Mining Methods at the Old Dominion Mine, Globe, Ariz.: Inf. Circ. 6237, Bureau of Mines, Feb., 1930, 21 pp.

[39] – Brown, U. E., Mining Methods of the Bunker Hill and Sullivan Mining and Concentrating Co., Kellogg, Idaho: Inf. Circ. 6407, Bureau of Mines, Jan., 1931, 9 pp.

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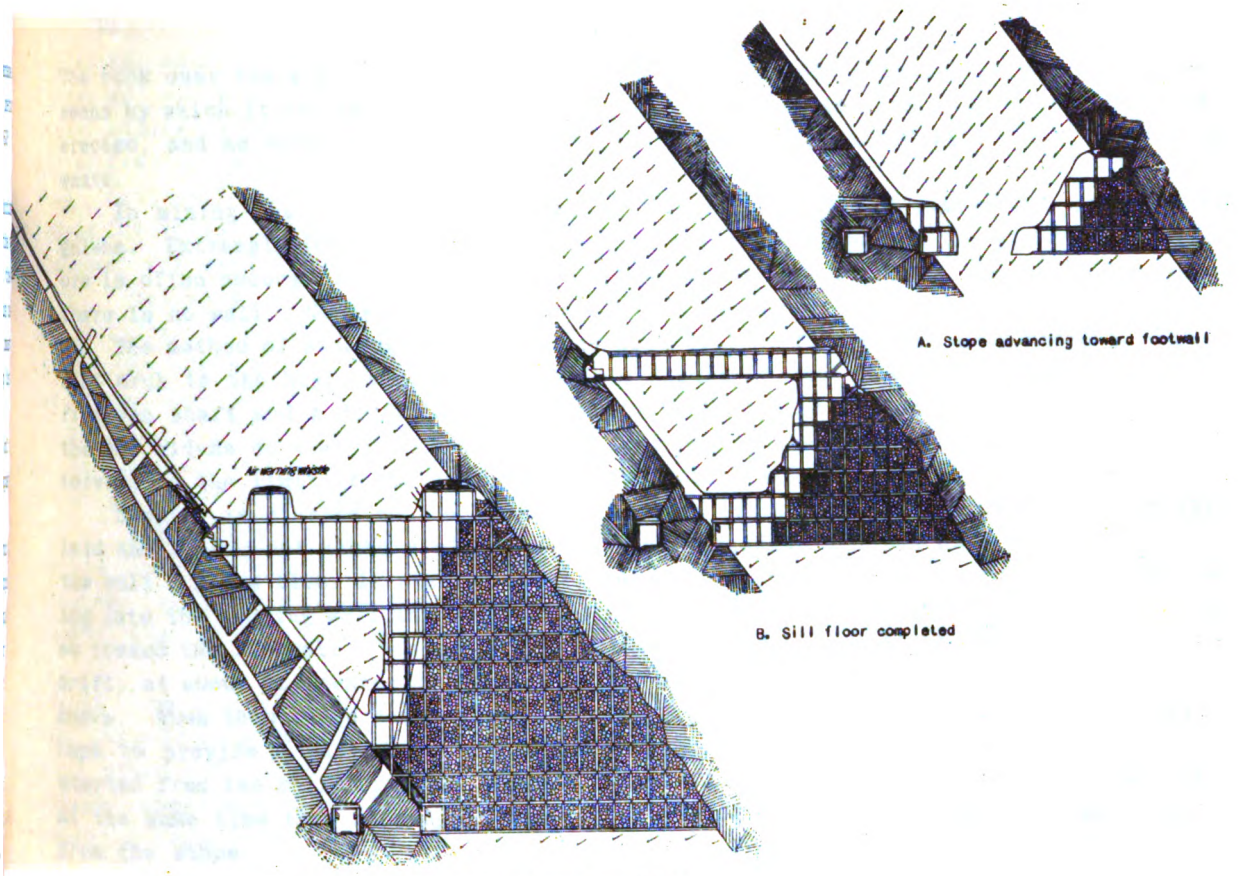
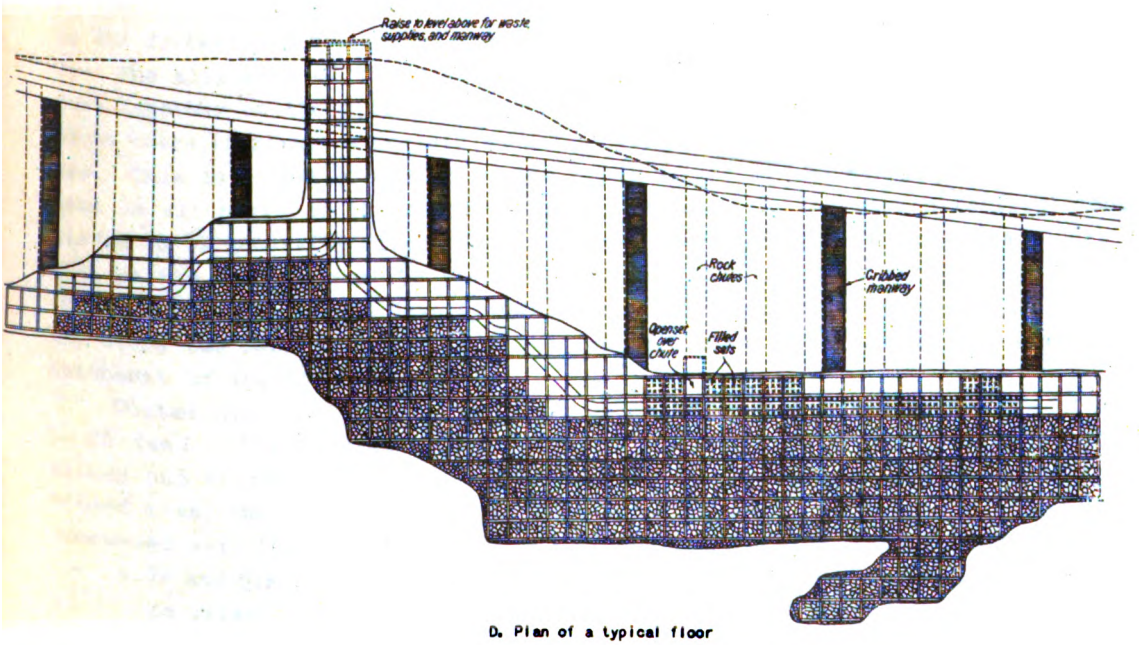


A. Stope advancing toward footwall

B. Sill floor completed

C. Stope development completed



D. Plan of a typical floor

Figure 35.- Square-set stoping at the Bunker Hill and Sullivan mine

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The rock over the ore is invariably heavy, and square-sets closely filled with waste is the means by which it can be safely supported. As rapidly as the ore is removed, square-sets are erected, and as soon as practical these sets are tightly lagged with slabs and filled with waste.

In mining the large irregular masses the practice is to remove all material showing galena. Extremely low-grade ore is therefore sometimes mined; on the other hand, high-grade ore is often uncovered. Ordinarily one well-defined wall is found, but never two; sometimes there is no wall. No two cross sections are alike, even when close together.

The method of stoping now in use has been evolved from a flat back stope through a low, flat arch to the high, sharp arch shown in Figure 35, C. The vein is cut by the crosscut from the shaft and a drift is run on the footwall to the extremities of the orebody. When the ore widens so that it can not all be included in the drift, crosscuts are driven at intervals to the limit of the ore on the hanging-wall side.

Stoping is started on the hanging-wall side of the vein. Sills covered with slabs are laid and square-set timbers placed. These are extended and the back row filled to support the wall. A new floor is started above the sill floor, the first two of square-sets extending into the hanging wall to obtain filling for the sill floor, after which stoping progresses toward the footwall. A steeply arched back is maintained at all times. From the footwall drift, at about the center of the ore shoot, a raise is started on the footwall to the level above. When this raise has been holed through, it is timbered with 6-foot posts and 10-inch caps to provide a waste pass and a timber pass with a manway between. Another drift is started from the shaft crosscut between 20 and 30 feet under the footwall. This is extended at the same time that stoping is being started and eventually becomes the main haulage way from the stope.

The next stage is shown in Figure 35, A. The stope is advancing toward the footwall and the footwall raise is completed. The drift under the footwall is being extended and the pillars of ore are being attacked. The various places where stoping has been started are connected. The first footwall drift is generally completed by this time and the boundaries of the ore have been determined. Filling for the stopes, until the line of sets is connected to the footwall raise, is obtained from the hanging wall.

The alignment of the square-sets may be imperfect where the several stoping sections come together on the sill floor, but this is considered an advantage. In a large timbered stope there is always a certain amount of longitudinal pressure as well as transverse pressure. This is probably because of the great weight of the hanging wall. It may not be evident in all parts of the stope nor always exerted in the same direction, though it is believed to be generally directed toward the wider parts of the stope. A change in the alignment of the sets allows the resultants of any such pressure to be taken up by the walls of the stope. The complete development of the sill floor is shown in Figure 35, B. The top of the stope has been connected with the footwall raise. Figure 35, C, shows the complete development of the stope.

Chutes are started from the drift under the footwall toward the ore at intervals of 15 to 20 feet. The hanging-wall portion of the stope is advanced by mining nearly vertical slices one or two sets wide. Additional floors are opened to keep a strong arch over the stoped area, and a nearly vertical face is maintained. At this stage the footwall raise is connected with the top floor by a row of square-sets; track is laid and waste is drawn from the raise and distributed by hand-trammed cars. The stope is worked so that the highest part is at the raise, thence sloping toward each end. This allows the waste and timbers brought in through the raise to descend to the place where they are to be used.

The sill floor is abandoned when the vertical face of the stope reaches the footwall (see fig. 35, C). One or more raises, to be used as ore passes, are driven from the haulage drift under the footwall. These raises are approximately parallel to the footwall and inter-

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sect the ore a short distance under the level above. From the main raises branch raises are driven to the ore, and if necessary these in turn are branched. This eliminates the use of long cribbed chutes, or the necessity for transferring the ore on the intermediate level. If the stope is very long, additional 3-compartment raises are driven on the footwall to the level above and the stope is developed at each raise in the manner already described. Such additional raises, not being needed until stoping is in progress, start on one of the higher floors from a row of square-sets driven to the footwall. Figure 35, C, shows the temporary slides used to get the ore into the chute and the waste into the sets to be filled.

Figure 35, D, shows the plan of a floor and illustrates the method of distributing the waste. In heavy or soft ground the square-sets at the face are lagged with slabs and filled, leaving an open set over the chute as shown by the dotted area. From the open set at the chute one set is cut toward the footwall and a section as many sets long as convenient is mined either upward or downward. In bad ground filled and open spaces alternate and at no time is a stope left unsupported by waste filling. Figure 35, D, also shows the rock chutes 15 to 20 feet apart in the footwall of the stope and cribbed manways 50 feet apart.

Ordinarily rock chutes and manways are not cribbed unless bad ground is enountered. If a raise contains both a chute and a manway, however, each is cribbed separately; the short raises driven from the haulage drift in the footwall to the stope are usually cribbed throughout.

Figure 35, C, illustrates the advantages found in mining by vertical slices. At this mine drilling the ore by uppers is much easier than by flat holes. The ore when blasted falls into the chutes. When sorting is necessary the ore is blasted on floors. The waste comes into the stopes at about the consistency of wet concrete and settles in the lagged square-sets to a compact mass, forming a very solid wall to support the stope. The lagged and tightly filled sets, being kept close to the face, limit the area in which blasted ore may be scattered. Good protection is provided for the miners and ventilation is better through vertical openings than in flat stopes. The high, sharp arch throws the weight of the ore on the footwall and the weight of the hanging wall on the solidly filled square-sets. This arch is developed early in the operation and carefully maintained until the stope is finished. The haulage way, being in solid rock, is not subject to settling. Rock chutes give greater storage capacity than timbered ones and require little repair.

Waste for stope filling is essential for the vertical-slice system of stoping and a supply must be available at all times. The supply of waste is derived from exploratory drifts and crosscuts and from sinking or raising shafts, and if necessary waste raises are driven into faulted zones where caving can be utilized.

For storage and distribution of waste a series of connected raises has been driven from No. 17 level to the Kellogg tunnel. Waste can be stored in the raise below any level or withdrawn from the section above for distribution. Waste is drawn to and from the raise to the places where used by a storage-battery locomotive and cars.

Square-set timbers consist of 12-inch round posts and 8 by 10 inch caps and ties. As shown in Table 2, a post-butting method of framing the sets is used. The tenons on a post are 4 by 4 inches in section, the top one is 7 inches and the bottom one 3 inches long. The small horns on the posts would appear to be a point of weakness, but little trouble is experienced from this source. The girts, being unframed and stronger than the caps, are placed parallel to the strike of the walls and the caps are at right angles to the strike.

Tabular and irregular orebodies up to 175 feet in height are mined at the Tintic Standard mine by taking out vertical slices.[40] The dip of the orebody ranges from 45° to vertical. A considerable part of the ore consists of a fine, sandy material intermixed with masses of heavy lead ore.

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[40] - Wade, James W., Mining Methods and Costs at the Tintic Standard Mine, Tintic District. Utah: Inf. Circ. 6360, Bureau of Mines, Oct., 1930, 21 pp.

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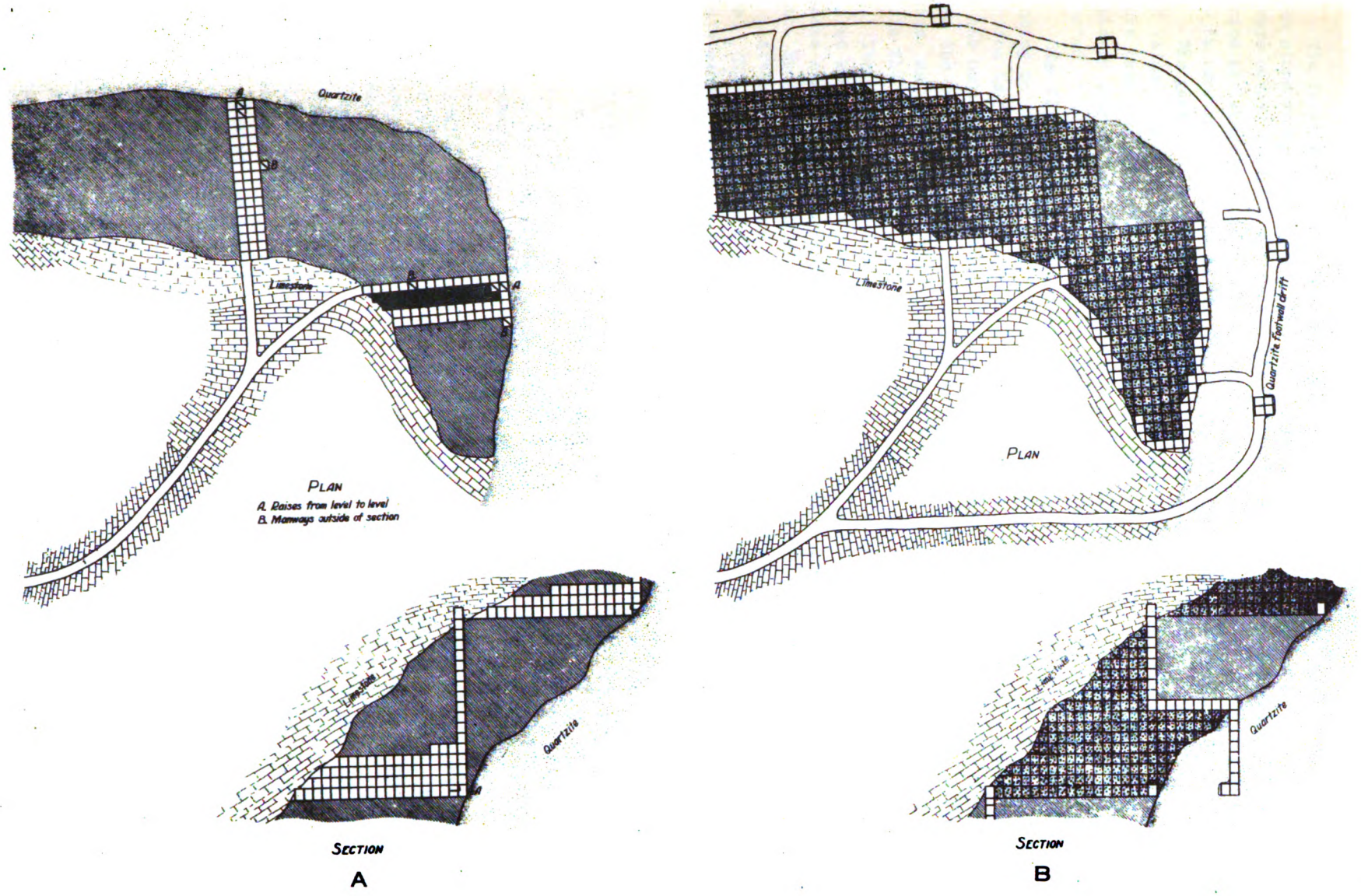

Figure 36.- Method of mining, Tintic Standard mine: A, First step in starting a stope; B, mining the upper part of a stope

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The first mining was done at this mine in following high-grade portions of the ore by open stope or square-setting without filling. In 1921, settling of the orebodies began, and severe caving resulted before the mined-out stopes could be completely filled. During this period shrinkage stoping and the Mitchell system of mining were tried and discarded. After the failure of these methods the present method of square-set stoping and filling was adopted.

The general plan of stoping for the past eight years has been to drive a vertical square-set raise from the footwall, at the level where the stope is to be started, to the level above (see fig. 36). The raise is the place from which a stope is started and through which waste is dumped from the level above when filling is wanted. For every stope (not section) started it is necessary to have at least one raise to the level above for waste filling.

The first section of a stope started at the raise is cut two or three sets wide, depending on the character of the ground; it extends from the raise to the hanging wall. This section is mined floor by floor as high as safety will permit, then filled; manways are left on the outside of the section at convenient places. These manways afford a place of attack when the next section is started besides giving access to any floor above without having to raise; as three sides are in solid material they are safe and less expensive to maintain than if in the filling.

The original section is completed to the hanging wall, or mined eight floors high and filled before a new section is started two sets wide from the sill on one side. While the second section is being filled a third section is started on the other side of the original one. By alternating from one side to the other a regular tonnage of ore can be maintained.

After a section has been mined and filling is needed it is thoroughly cleaned of broken ore. The floor lagging above the sill floor is taken up and nailed to the inside of the posts against the unmined ore. The gob lagging is placed 2 inches apart. A tight floor of 2-inch lagging is placed on sills and covered with a foot or so of refuse timber which forms a mat. The mat should not exceed 1 foot if excessive settling is to be avoided.

After a number of sections have been mined a filled stope with a vertical face of ore on the footwall end exists. This ore is mined in the same manner by starting a 2-set section from a raise and advancing up the footwall. A footwall drift, with raises to the eighth floor (see fig. 36, B) affords an outlet for the ore above this floor, thus eliminating the necessity of keeping passages open through the filled stopes. The floor of the sections on the footwall are not lagged before filling, there being no ore underneath to be mined from below.

Practically all stopes produce three different types of ore, which are shipped separately, besides waste. Each type of ore is broken separately when possible, otherwise sorting must be done. It is necessary to have more stopes operating than would be needed if only one type were produced, to insure a fixed tonnage of any one product.

The ideal condition for square-set mining is in massive ore that will settle on the timbers gradually. This gradual increase in weight on the timbers, as mining is being done, tightens the timbers without excessive crushing. Square-set stoping and filling can be done in a systematic way with these conditions prevailing.

Orebodies at the Tintic Standard are not of the ideal type. In fact, there is nothing regular about the ground, and every kind of condition, from solid ore to material as fine as sand, can be expected. The result is that few sections can be mined floor by floor and filled. If ground will not stand while one floor is mined, then a variation in the mining practice is used, working from top down by floors, or working from top down by vertical cuts, or combinations of these methods. It is sometimes necessary to make a section only one set wide when the ore is sandy in texture.

As a vertical section through the orebody in some places is 175 feet high, settling of stopes during and for a period after filling must be met. Stope filling will settle as much as 7 feet between levels 120 feet apart before it comes to rest. This causes great distor-

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tion of the timber and settling of the filled stope from the level above, leaving room for movement of the hanging wall. Timbers in the sections mined along the sides of these filled stopes are affected considerably. Cutting caps within the fill away from the outside line of posts was experimented with, but was not found to be of sufficient value in preventing distortion to be maintained as standard practice. It has the further disadvantage of cutting a tie that materially supports the outside line of timbers.

The best method found to combat settling under the conditions of this mine is to keep filling as close to mining as possible, allowing the stopes to settle during the period of mining. By so doing it is possible to get the minimum of movement of the fill on the level above, after mining under its sills.

The size and framing of the square-sets are shown in Figure 4, E. Further data on the sets have been given in Table 2. The method of placing the square-sets has been described under "Placing Square-sets" (page 26).

Vertical slices are used at the United Verde Extension mine, Jerome, Ariz.[41] Because of the heavy, massive nature of the ore in the main orebody, the richness of the ore, and the necessity for mining in such a way that no blocks of sulphide ore are allowed to move and generate heat, only the square-set system of mining with stopes tightly filled with waste has ever been used in the main sulphide lens. By using this system, complete extraction of the main orebody has been possible with practically no dilution. Moreover, it has allowed careful prospecting of the walls, which has resulted in finding many small rich lenses of ore that would otherwise have been missed.

A typical stope is shown in plan and section in Figure 37, A. The stope sections are usually three sets wide in fairly solid ore and two sets wide in the heavier ground. If the ore is very badly broken it is sometimes removed in slices a single set in width. Slices are taken 100 feet high, as that is the interval between levels throughout the mine. The length of the slice may be anything to suit the conditions, but usually is from 10 to 20 sets. Ore chutes are placed in about every fourth set, and alternate chutes have manways beside them. By spacing chutes in this manner and leaving slides with grizzlies in adjoining sets, as shown in Figure 37, A, the shoveling of ore into chutes is virtually eliminated. If no weight develops on the timbers after one floor is removed, another is removed and sometimes several more are taken out before filling with waste. This reduces the cost of mining, as most of the ore rolls to the chutes and a large part of the fill can be run into place by gravity. When several floors are mined before filling, the timber is protected from the fall of the blasted ore by placing grizzlies of 70-pound rails, 6 feet long, held in metal holders, immediately below the mining floor. By using metal holders the grizzlies are moved very readily and placed where needed. After one section is finished it is filled entirely, except the chutes and manways needed for entrance to and mining of the next slice. The chutes also serve for running waste into the new section. By having a waste chute in about every sixth set and mining several floors before filling there is very little shoveling of fill. If conditions are such that the waste will not spread, a light metal gob chute is placed in the chute and the waste spread with a car or wheelbarrow. Figure 37, B, shows the details of the chute.

In the heavier sulphide stopes square-set timber consists of 10 by 10 inch Oregon fir. In the lighter ground 8 by 8 inch timber is used; in the sill floor gangways in the heaviest ground all timber is 12 by 12 inch.

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[41] - D'Arcy, Richard L., Mining Practice and Methods at the United Verde Extension Mining Co., Jerome, Ariz.: Inf. Circ. 6250, Bureau of Mines, Feb., 1930, 11 pp.

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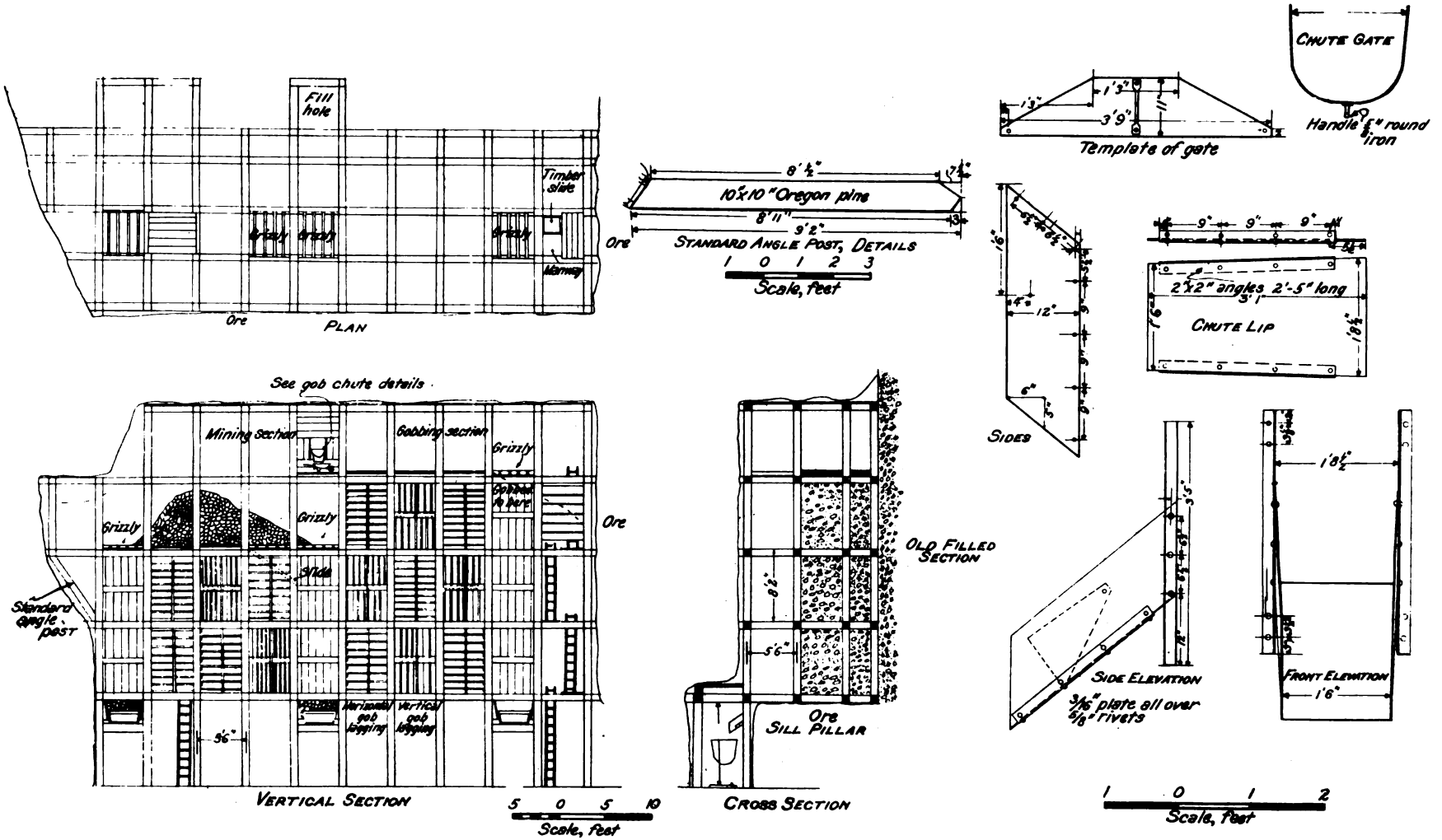

A. Plan and sections of a typical stope

B. Details of a metal gob chute

Figure 37.- Square-set stoping at the United Verde Extension mine

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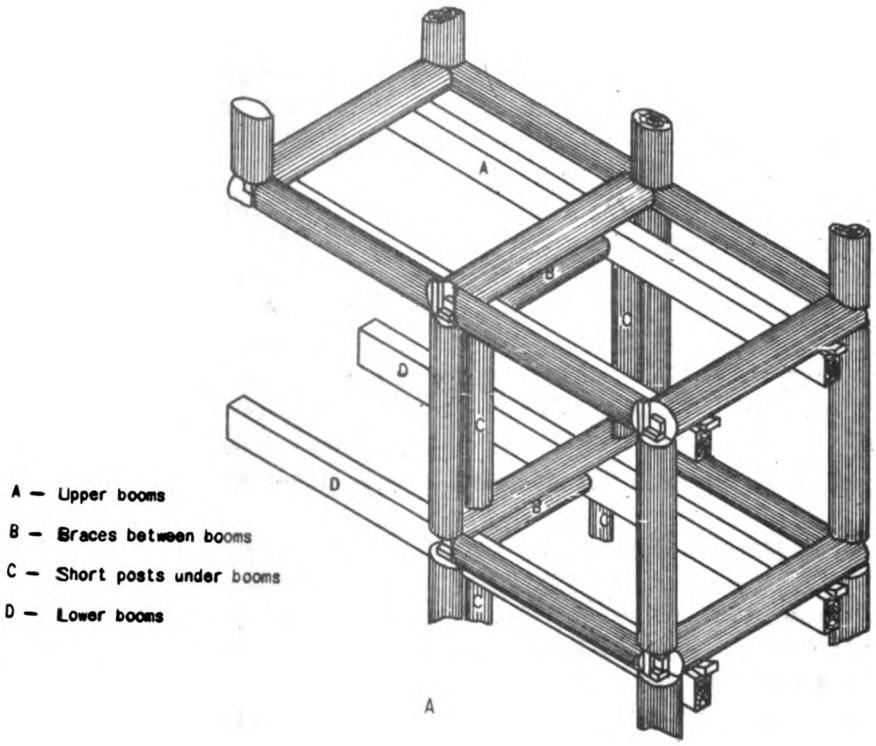

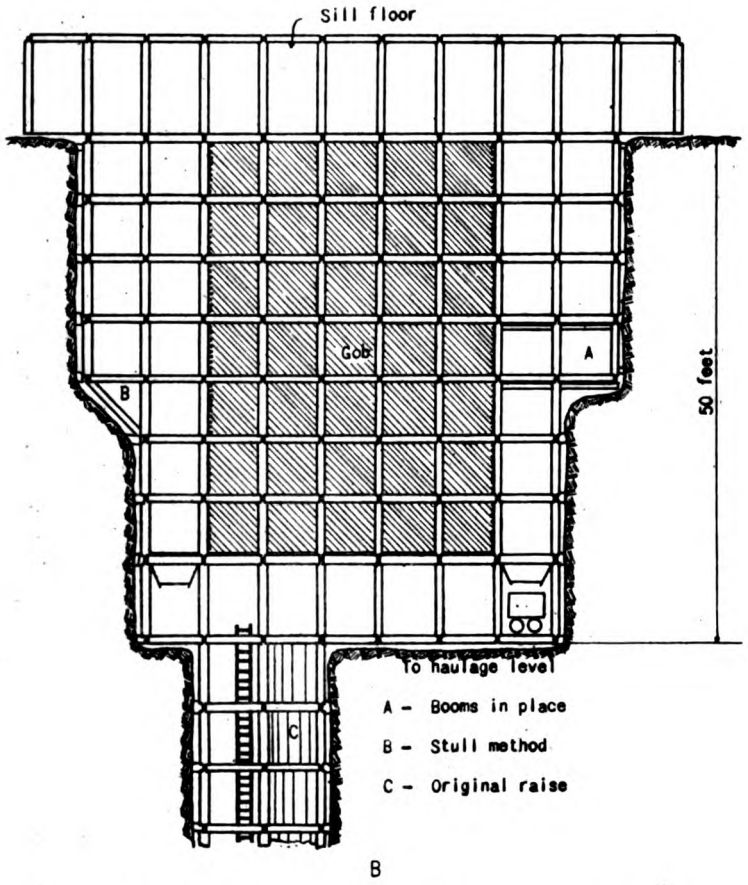

Figure 38.- Method of underhand stoping, Black Rock mine: A, Method of using booms; B, section showing underhand stope

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Vertical Downward Sections

In sandy or running ore where the ground is such that openings will not stand long enough for a set to be placed, the ore may be mined underhand in vertical sections. The number of sets that can be taken out on a floor in the vertical sections depends upon the pressure from the sides.

This method of mining is illustrated at the Black Rock mine at Butte.[42] In underhand square-setting at this mine, a raise is first put through from one level to another in the orebody to be mined. Starting from the raise a cut is taken into the orebody on the floor below the upper sill. "Booms" are then put in place, catching the bottom of the sill timbers (fig. 38, A). "Booms" are 5 by 10 inch timbers 13 feet long. There are two methods of holding the timbers above while the ground for the set below is being taken out: (1) If down weight is excessive, booms are used for every set. In this case two pairs of booms are used, the upper pair being moved down as mining progresses. (2) If side weight is excessive a diagonal stull will be sufficient to hold the cap in place while the ground is being worked out for posts.

After the first set is in, the ground for the set directly below is taken out. Mining progresses downward in this manner for about 50 feet. At this point an intermediate level along the footwall is established to be used for tramming ore back to the raise chute (fig. 38, B). Starting at the top another set is mined down. This cut is taken from the first set toward the hanging wall. Mining is continued following this procedure until a line of sets from foot to hanging wall is mined out vertically from the upper sill to the intermediate floor. The next line of sets is then mined out in the same manner. As mining progresses, waste filling is put in and held in place by small poles or broken lagging. Usually a complete column of sets is filled at one time, consisting of one set on each floor for the entire height of the stope. Two sets from top to bottom are kept open at all times, and are used for a chute and manway. One set in each line is always in use temporarily as a chute from the stope to the intermediate floor. It is not necessary to line the sets being used temporarily as chutes.

As soon as a few lines of waste are put in between the original raise and the breast of the stope, a similar stope may be started from the raise in the opposite direction. When this new stope has advanced two lines the original raise is abandoned and filled from the intermediate level to the upper sill. The ore below the intermediate is worked in the same way after the upper half is worked out. Caps are used for posts in underhand stoping. The upper sill is usually abandoned before or during mining operations below. Access to the stopes is gained by footwall laterals and short crosscuts. The waste from driving these openings is conveniently used for stope filling.

An underhand method of stoping for mining crushed ore alongside filled stopes with unframed stringer sets has been used at the Calumet and Arizona mine.[43] Starting at a raise, three sets on a floor, making a section 5 by 15 feet in size, are mined and timbered with round 7-foot posts, 5-foot caps, and 15-foot sills. In mining out the next floor below, the posts are stood on 10-foot sills placed at right angles to those above. Then a second 10-foot sill parallel to this and 5 feet away is placed. The sills on adjacent floors are at right angles to each other; those running across the stope are 10 feet long and those running the length of the stope are also 10 feet long.

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[42] – McGilvra, D. B., and Healy, A. J., Methods of Mining at the Black Rock Mine, Butte & Superior Mining Co., Butte District, Mont.: Inf. Circ. 6370, Bureau of Mines, Dec., 1930, 16 pp.

[43] – Dickson, Robert H., Mining by Ratterree Modification of Underhand Square-Setting: Eng. and Min. Jour.-Press, Jan. 27. 1923, vol. 115, p. 191.

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The square-set system of mining is used in the Junction orebody of the Calumet & Arizona mine. Depending upon ground conditions, successive sections may be square-setted, cut-and-fill sections may be taken up, leaving alternate pillars to be mined by square-setting, or successive or alternate sections may be mined by the Mitchell slice method. In using this latter method a row of lead sets is taken up to the top of the ore or the level above around a block four or five sets wide and up to 10 sets long. The part of the section inside of the sets (two or three sets wide) is then mined downward and filled. Stringers are placed between the sets on either side as room is made in breaking the ore. The lead sets next to the ore are not filled; they are used in mining the adjoining section. The Mitchell method is described under "Recovery of Vertical Pillars," page 63.

Slot or Copper Queen Method.- A method of stoping with downward vertical slices in which the blasted ore falls into slots previously made has been used successfully at the Copper Queen mine. In the limestone section of this mine the orebodies consist mainly of irregular masses of sulphides. Three general methods of mining are followed, depending mainly on the structure of the ore and the necessity for selective mining. In places where the ore will stand, a cut-and-fill method is used. Although the ore is hard to break, planes of weakness extend through the orebody in many places which permit masses, sometimes weighing hundreds of tons, to settle or fall where the back is not well supported. In such cases either a regulation square-set or a top-slicing method is followed. The method of laying out the stopes is the same whether the space is to be filled or the back allowed to follow downward. The stopes are filled when subsidence of the country over the orebody is undesirable, or where the outline of the orebody is very irregular and where sorting or selective mining is necessary.

The advantage of the method of laying out the stope is that top-slicing can be changed to a square-set-and-fill method any time that selective mining may become necessary, as when metals are low in price. In top-slicing the floors are timbered with square-sets, the only difference from standard square-set practice being that the sets are on 11-foot rather than 8-foot vertical centers.

The orebodies are developed by running a drift through them lengthwise with crosscuts from the drift on 50-foot centers. Raises are also put up on 50-foot centers to the top of the orebody or to the level above (fig. 39). This is called "stope development" at the Copper Queen mine, and the average cost is $0.30 per ton of ore mined.

After the preliminary work is done, slots on 20-foot centers are taken up through the orebody to the level above or the top of the ore. The slot is one set wide and two sets long on the first floor. The length is increased one set on each side of the center for each additional floor until the maximum length is attained. Although the sections are infrequently over 50 feet long, occasionally slots will be run 14 sets or 70 feet long at the top to reach bulges in the orebody. Usually the orebodies are mined in one lift.

The manner of placing the slots depends mainly on the shape of the orebody. It is planned that all ore except relatively small offshoots be within 15 feet of a slot. In a large orebody a number of parallel slots will be run; in a smaller deposit only one main slot may be needed. Slots at right angles to each other may be used in orebodies of nearly circular outline or for mining bulges of a large orebody. Two square-sets at one side of the middle of the main slot are carried up along with the slot. The raise compartments are lagged One is used for a manway and the other for getting supplies into the slot or later into the stope. The end sets on the slot are anchored into the solid ore. If the ground is heavy, a set with a batter post as used for drifts will be put in. Grizzlies consisting of 10 by 10 inch timber are placed over every alternate set in a slot to break the fall of the ore. The sets of the slot are not lagged and are usually kept full of ore. The ore is drawn from the slots through a chute in the middle of each. After the slots have been fully developed,

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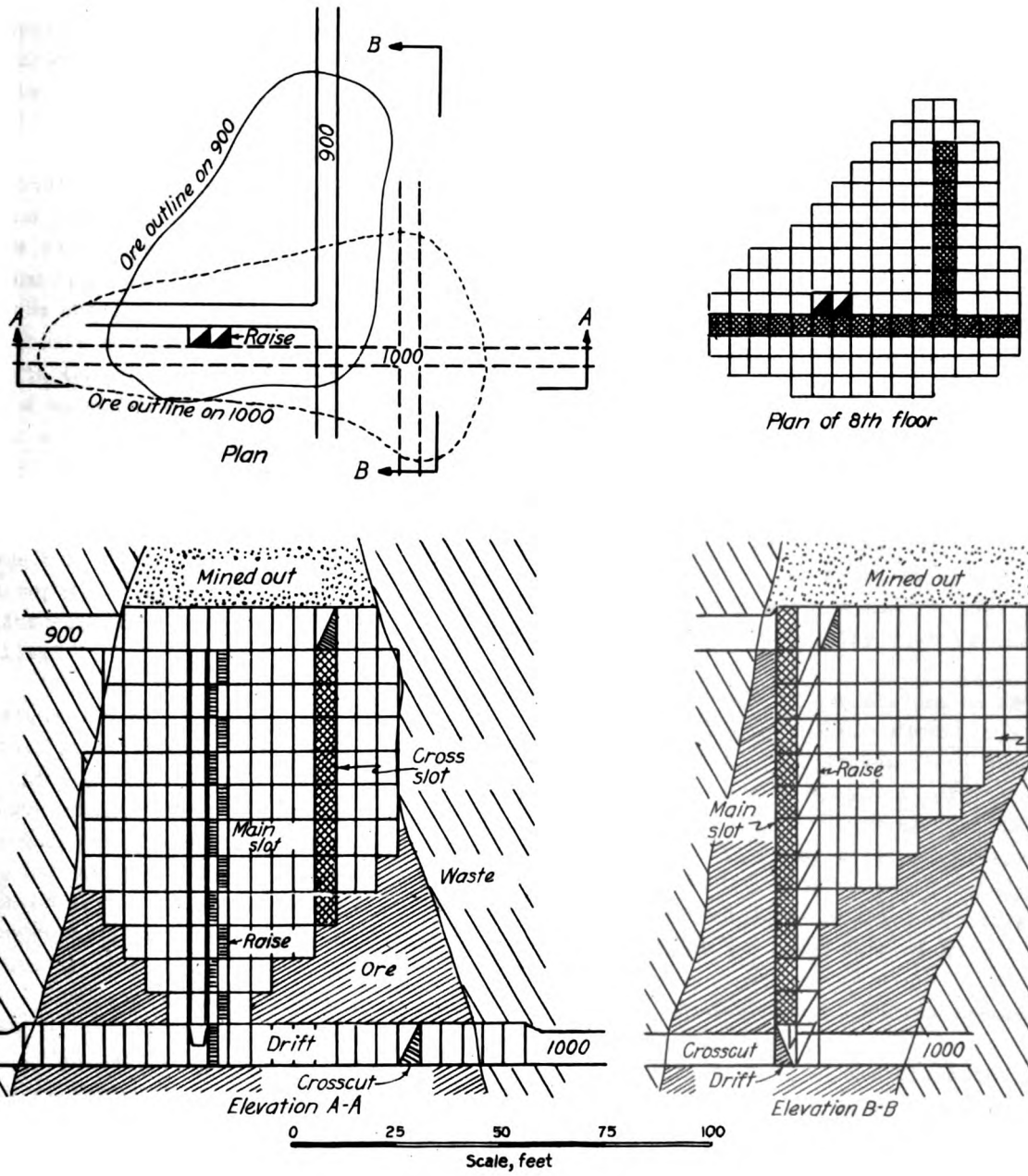

Figure 39.- Typical example of slot method of square-set stoping at Copper Queen mine

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stoping proper begins, usually at the top. As most of the ore is within 15 feet of a slot, little shoveling is necessary.

When the stope is top-sliced a floor at the top of the ore is taken out and square-sets put in. Sills are placed and a timber mat is laid. Each floor is connected to the service raises, which are kept open between levels until the stope is finished. Where a stope in a large orebody is to be filled and ground conditions are suitable, every alternate panel between slots is mined, timbered with square-sets, and then filled. The other panels are then taken out by the Mitchell underhand method, described later. As the first panels are mined the outside timbers of the boundary slots are gob-lagged and tied together with lengths of old hoisting cable. Stringers are placed as needed when the pillar panels are mined.

The first panels are usually mined and timbered downward. Occasionally, however, the conditions may be such that they are mined upward, beginning at the bottom. Where necessary the panels will be filled as mined, but usually one can be entirely removed before filling is necessary. The filling is generally dropped into the panels from the level above. In changing over from top-slice to a filled stope, filling is brought in through lagged sets, from outside, or sometimes by tapping the gob over the mat, depending on whether upper levels have to be held or not. The slots are also filled after the last adjoining panel is mined. With top-slicing, one panel on each floor is taken at a time, and an attempt is made to keep the descending mat level. When filling is used, the usual practice is to take the panel out as a vertical section.

In mining downward the ore left near the bottom of the stope under the notched ends of the slots is taken out on each floor as reached. Short vertical or inclined untimbered raises, locally called "bean holes," are run from the drifts or crosscuts to receive this ore when it is over 15 feet from a slot. In case an offshoot is not large enough to justify a separate raise, the ore is brought in wheelbarrows to the nearest slot. When a stope is mined upward, the ore is taken out through the short raise after the rest of the stope is filled.

The system has extreme flexibility—a complete extraction of the ore can be obtained and extensions of the ore in the wall can be followed. The narrow panels permit the ore to be mined with minimum shoveling. In heavy ground the sets can be filled soon after being placed. In good ground a panel can be removed before filling. The ore is always supported by timber, which minimizes the danger of falls. If any settling of large blocks occurs, they can be held up until broken and the space timbered and filled. If after a stope is started it is found that portions of the orebody are loo low grade to mine under existing conditions, it can be left in place to be mined later when the price of metals is higher. Usually where an appreciable part of the orebody must be left, the stope is mined upward at the time the slots are cut.

The general development charge per ton of ore is $0.60 per ton. During normal times 14 tons of ore is obtained to each foot of general development work.

The main advantage of cut-and-fill method of mining at the Copper Queen is the appreciable saving in the amount of timber used. The amount of ore broken per man-shift is less than with either the square-set-and-fill or top-slice method. Slightly more timber is used in top-slicing than when the sets are filled. The average cost for both methods is $0.40 per ton.

Recovery of Vertical Pillars

As stated before, the stope-and-pillar system is used at some mines. In relatively low-grade deposits or where open-stope methods are used the pillars may be undercut and caved; the lower cost of extracting the pillars by this method may more than compensate for loss of

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ore inherent to the system.

In high-grade deposits where the loss of mineral would be serious the pillars usually are mined by square-setting methods. The method used depends upon the size and shape of the pillar and the condition of the ore. Wide pillars usually are mined by standard square-set methods. Either horizontal or vertical slices may be taken. Where the ground is heavy or crushed it usually is mined in vertical sections. Vertical sections either upward or downward are taken out, as previously described, for regular square-set operations. Narrow pillars generally are mined by special methods; either overhand or underhand mining may be followed.

The method used in relatively wide pillars is illustrated by the practice at the United Verde mine. At this property 64 per cent of the ore is extracted by cut-and-fill methods.[44] The cut-and-fill stopes range from 30 to 160 feet across and 60 to 200 feet long. Pillars left between these stopes usually are either 30 or 40 feet wide.

The principal orebodies occur along the contact of massive sulphide and schist. The massive sulphide generally is very hard and dense, and stands well over large areas without timber support, except for an occasional bulkhead under a loose slab or where weakened by an andesite dike. This permits mining by cut-and-fill and shrinkage methods.

Square-setting is used in the extraction of the vertical pillars between cut-and-fill stopes, and also in some areas in the main stopes where the ground is heavy. Twenty-seven per cent of the ore at the mine is extracted by square-setting. The size of square-set stopes varies considerably. In the vertical pillars the sections are necessarily small, rarely exceeding 35 sets in area. The sets are 5 feet 6 inches square by 7 feet 2 inches high. The timber used is all 10 by 10 inch native pine. The shoveling floor is made of 2-inch plank, and the working floor of 3-inch plank held on by 2 by 2 inch lagging strips nailed to the caps and girts.

The method of taking out the section is shown in Figure 40. Never more than two floors are opened at a time, and the fill is kept as close behind the shovelers as possible. The fill is introduced through a raise to the level above and distributed in the stope by means of narrow end-dump cars running on sectional track with short-radius curves so as to obviate the necessity of turntables or turnsheets in the stope. The narrow car and special track allow plenty of clearance between the car and the posts.

At the Homestake mine, Lead, S. Dak., 60-foot stopes are mined by shrinkage, leaving alternate 40-foot pillars which are mined by square-setting. In addition, a crown pillar 25 feet thick is mined by square-setting at the top of each shrinkage stope. Fifty-five per cent of the ore is mined by square-setting and 45 per cent by shrinkage. After a shrinkage stope is finished it is filled. The crown pillars are taken out, then the vertical pillars are mined. The square-set sections in vertical pillars are taken up in vertical rather than in horizontal sections, as at the United Verde mine. As the level interval at the Homestake (150 feet) below the 1100 level is too great to carry up the stopes in one lift, the pillars are mined in two parts. A crosscut is driven in the pillar midway between levels from a manway raise on the footwall (fig. 41).[45] Another crosscut is run a short distance below the top of the pillar to provide ventilation. A raise is driven at the hanging wall to the sublevel for an ore chute. Beginning at the footwall three lines of sets are taken up across the end of the pillar. One line of sets is kept open to assist in mining the next section and the others filled. A line of sill sets is also kept open to the footwall row along the

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[44] – Quayle, T. W., Mining Methods and Practices at the United Verde Copper Mine, Jerome, Ariz.: Inf. Circ. 6440, Bureau of Mines, Feb., 1931, 31 pp.

[45] – Ross, A. J. M., Ore Extraction and Transportation at the Homestake Mine: Eng. and Min. Jour., vol. 132, Oct. 12, 1931, p. 330.

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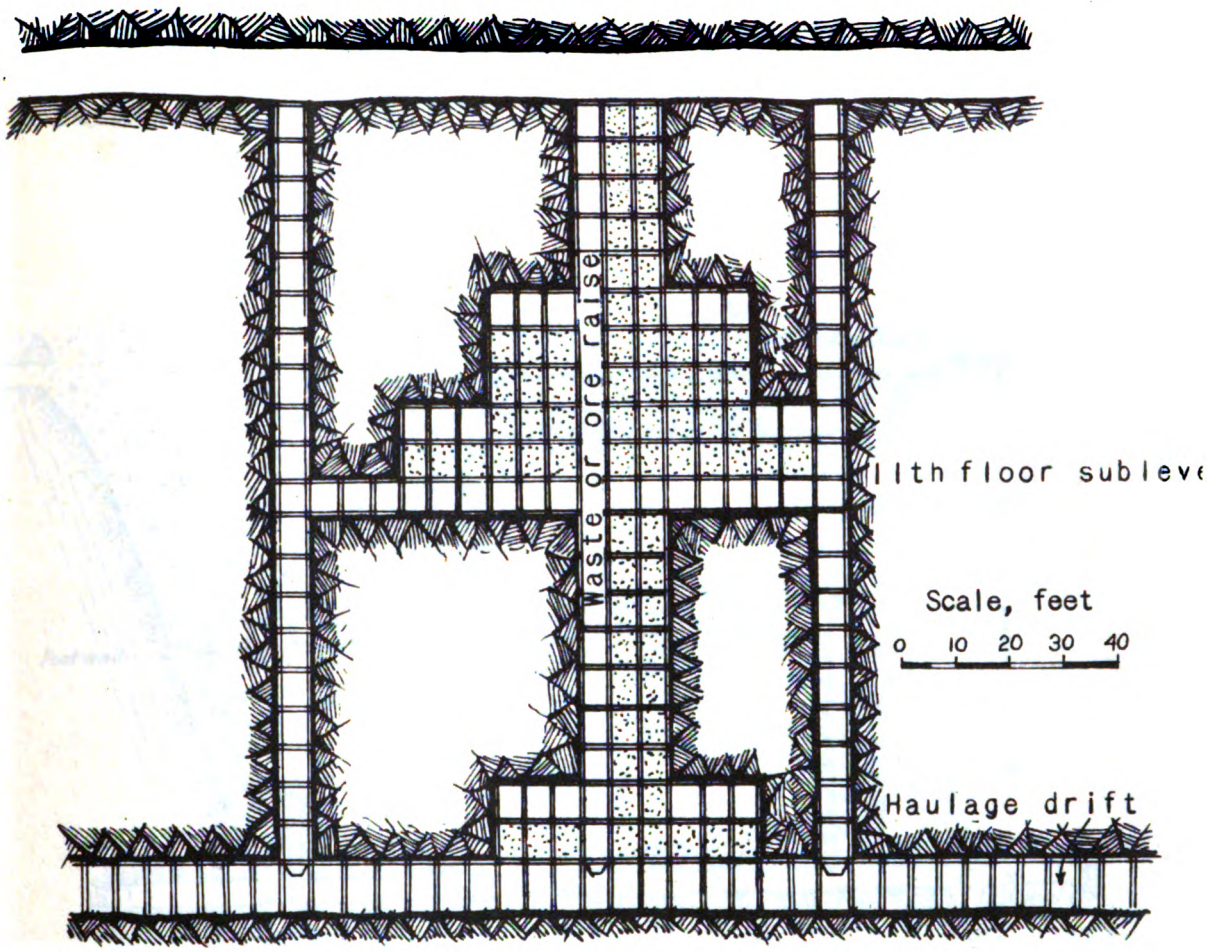
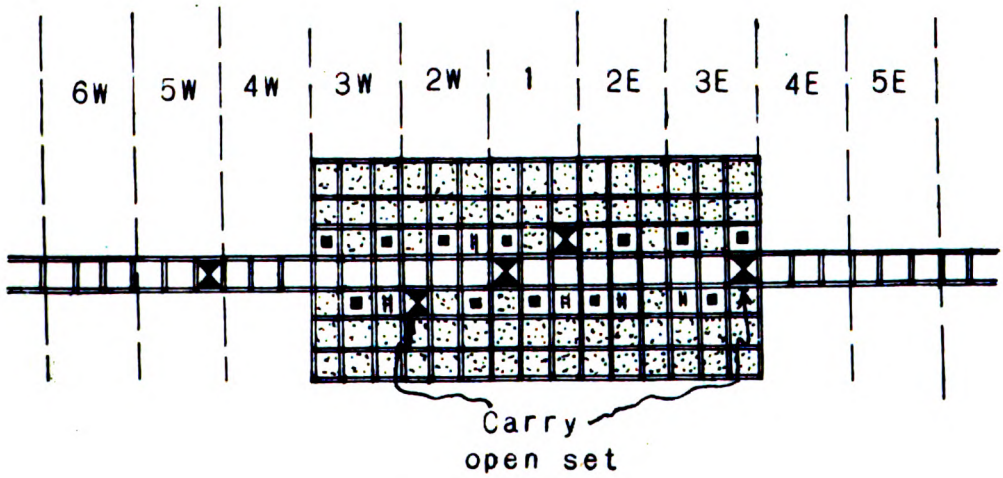


Longitudinal vertical section



Plan of 11th floor sublevel

Figure 40.- Square-set method of mining vertical pillar at the United Verde mine

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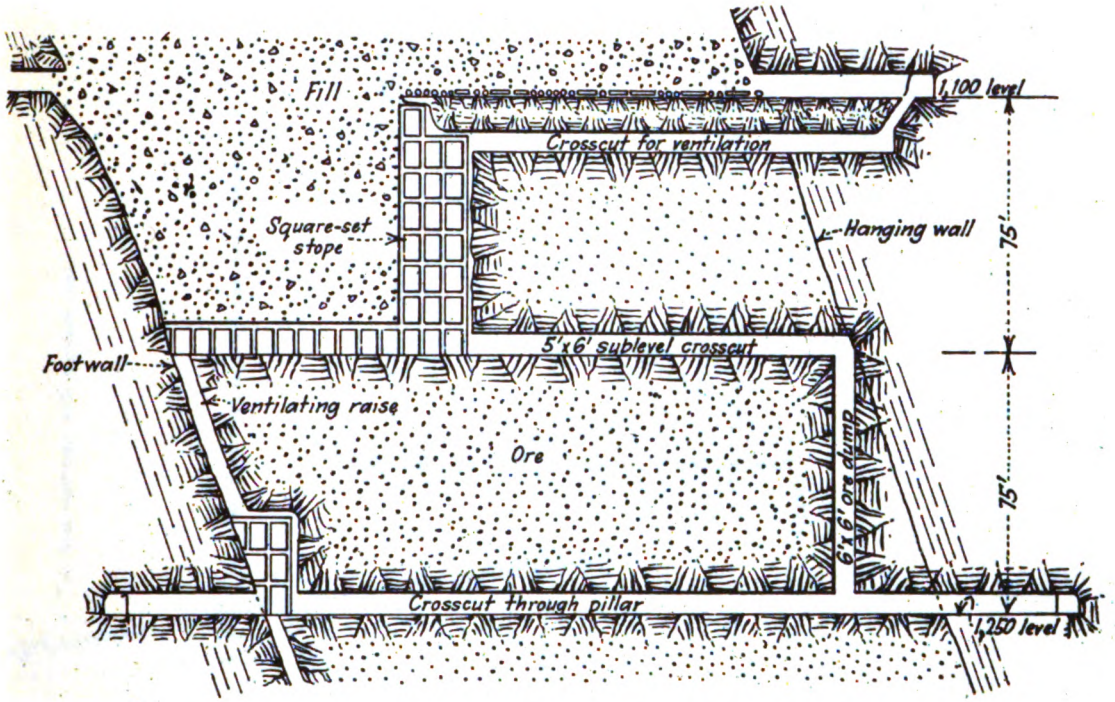

Figure 41.— Method of mining vertical pillars at the Homestake mine

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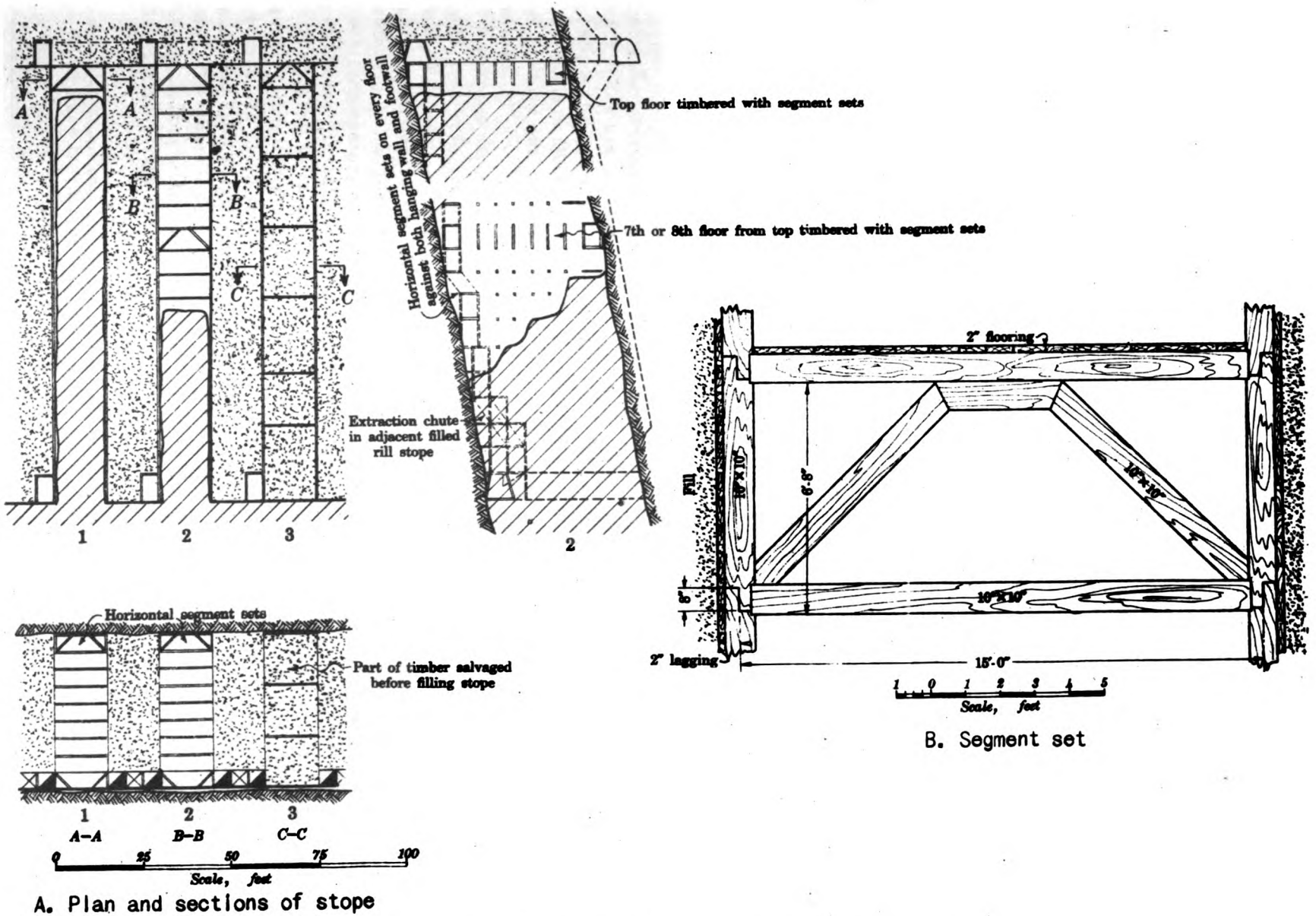

Figure 42.- Mitchell slice method at the Magma mine

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center of the stope. Waste from a glory hole is used for filling so long as the entrance over the stope can be kept open, after which the waste is obtained from the filled stope above. The ore is drawn in a car at the bottom of the section being mined, which is pushed by hand to the ore raise. After one section is filled the next is mined. The same general method is used for the lower half of the pillar as the top part. A contract system is used for paying the miners. The contract price includes explosives and labor of extracting the ore, standing the timber, and filling the sets. The standard price for this work is $0.94 per ton. In badly crushed ground $1.09 per ton is paid, and in extremely bad ground $1.24. The average earnings of the contractors in both vertical and crown pillar stopes for September, 1931, was $5.94 per shift. All of the men working in a stope participate in the contract.

Square-sets are 5 feet 6 inches center to center in plan and 8 feet 3 inches high. A post-butting type of framing is used (Table 2). Local timber ranging from 11 by 11 inches to 14 by 14 inches in size is used for the sets.

The same general plan as followed at the United Verde or the Homestake mines may be used for extracting narrow pillars where the ground stands fairly well. Where the first stopes are mined by square-setting, sets at the pillar are lagged off and kept open for extraction raises for mining the pillars. The level interval and the condition of the ore determine whether the pillars are mined in one or more lifts.

The so-called Mitchell slice method is used at some mines in the Southwest for extracting narrow pillars by underhand methods. Although the method has only a limited application, it is successfully used in a few orebodies where the right conditions prevail. It can not be used in extremely heavy ground.

In mining by this method alternate stopes have been taken up, usually by square-setting, and then filled. The pillars usually are 14 to 16 feet wide. The gob lining of the original stopes on either side usually is tied together with discarded hoisting cable. As the pillars are mined downward, square-sets or framed stringers are placed to hold back the filling on either side. Stringers when used are placed at vertical intervals corresponding to the height of sets. The ore is blasted into a line of open sets left in one of the outside stopes.

Where the conditions are favorable and stringers can be used, less timber is required in the pillars than in the first stopes. The pillar ore can be mined rapidly and the whole block usually can be mined at less cost under the right conditions than if square-setting were used.

The Magma Copper Co. uses the system in orebodies over 15 feet wide. Sections of the vein 16 feet wide are mined to the level above by a cut-and-fill method, leaving pillars 14 feet wide between. The pillars are then mined by a modified form of the Mitchell method.[46] In using this method the top of the pillar is shot out and a line of segment sets is placed immediately below the filled sill floor of the finished stope above (fig. 42). If added support is necessary to hold the ground, the second floor down may likewise be timbered with segment sets. In this case the segment sets are placed in an inverted position.

The pillar is mined on about a 40° slope down toward the footwall; the broken ore runs by gravity into the square-set raise which was used in the adjoining rill stope. As stoping progresses, 10 by 10 inch stringers are placed across the stope at intervals of 7 feet vertically and upon 5-foot centers horizontally between corresponding posts previously placed in the rill stopes. Only enough ground is broken at one time to make room for one stringer. Drilling is done with jackhammers and practically all holes are drilled flat from staging nailed on the stringers.

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[46] - Snow, Fred W., Mining Methods and Costs at the Magma Mine, Superior, Ariz.: Inf. Circ. 6168, Bureau of Mines, Sept., 1929, 32 pp.

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Grizzlies consisting of square-set timbers as used in the rill stopes are lowered to the set below each time a new cut is started. A ladderway is carried down on the stringers as mining proceeds. Both manways in the extraction raises are also maintained. Careful inspection of all stringers in the pillar stope is made during each shift as mining proceeds downward. A light floor is carried across the stope a few sets above the miners to guard against the falling of rock that may have been left lying on the stringers.

In addition to the segment sets placed at the top of the pillar, horizontal segment sets are placed against both footwall and hanging wall at intervals of 7 feet vertically and are lagged tightly. These sets are similar in construction to the vertical sets. Both hanging wall and footwall at this mine are heavy. As a precautionary measure, vertical segment sets are also placed 50 feet below the top; then if the ground starts to move, a floor can be laid at this point and the top of the stope filled with waste. A sill floor is laid at the intermediate level and the stope above is filled. The lower half of the pillar is then mined in the same manner. About 75 per cent of the stringers are salvaged as the filling is put in. The crew for a pillar stope consists of two miners and one mucker. A good crew will mine from 16 to 25 tons per man per shift in an average pillar.

At the United Verde Extension mine a system of mining badly broken pillars by a modification of the Mitchell slice method as shown in Figure 43 has been quite successful. A small square-set cut is first taken and the top of the sets is tied across with timber stringers, then the sides are sliced downward.[47] On most of the producing levels in the main orebody the mining has been done in such a way that pillars usually about six sets wide have been left over the main extraction gangways, extending vertically from level to level. These pillars have been standing in some cases for many years while the ore on both sides and on the level above has been removed. Resultant movement has in many instances thoroughly broken these pillars so that they would be very difficult to mine by ordinary square-setting from the bottom upward. Moreover, the gob lining between the pillars and old stope sections is often found to bo rotten and broken. In taking the small square-set slice up through the middle of the pillar, the old chute and manway in the section previously mined and filled is used as a cutting point. A series of 10 by 10 inch timber stringers from pilot sets to the old gob line is used in coming downward. Quite often this ore between the sets and the old gob can be taken down by the use of a bar alone, without the use of explosives. If the old gob line is broken or rotten it is blocked back by stulls between the stringers and new cross lagging. After one half of a section is finished it is filled with waste dumped in from the level above, and the other half is mined the same way. After all the mining is completed everything is filled except a chute and manway on the advancing side to be used as a cutting point for the next slice.

Recovery of Horizontal or Crown Pillars

In coming up under a mined-out portion of a wide orebody by the cut-and-fill or shrinkage methods the block of ground immediately under the level usually is taken out by square-setting. The height of the crown pillar to be mined by square-set methods depends upon the width of the ore and the physical conditions of the rock and ore; it ranges from 10 to 50 feet. In narrow veins the filling in a worked-out stope above usually can be held back by stulls placed between the walls, in which case square-setting will not be necessary.

The removal of a pillar beneath a large worked-out stope causes enough subsidence to prevent efficient tramming through the old drifts below the stope. At the Minas de Mata-

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[47] – D'Arcy, Richard L., Mining Practice and Methods at the United Verde Extension Mining Co., Jerome, Ariz.: Inf. Circ. 6250, Bureau of Mines, Feb., 1930, 11pp.

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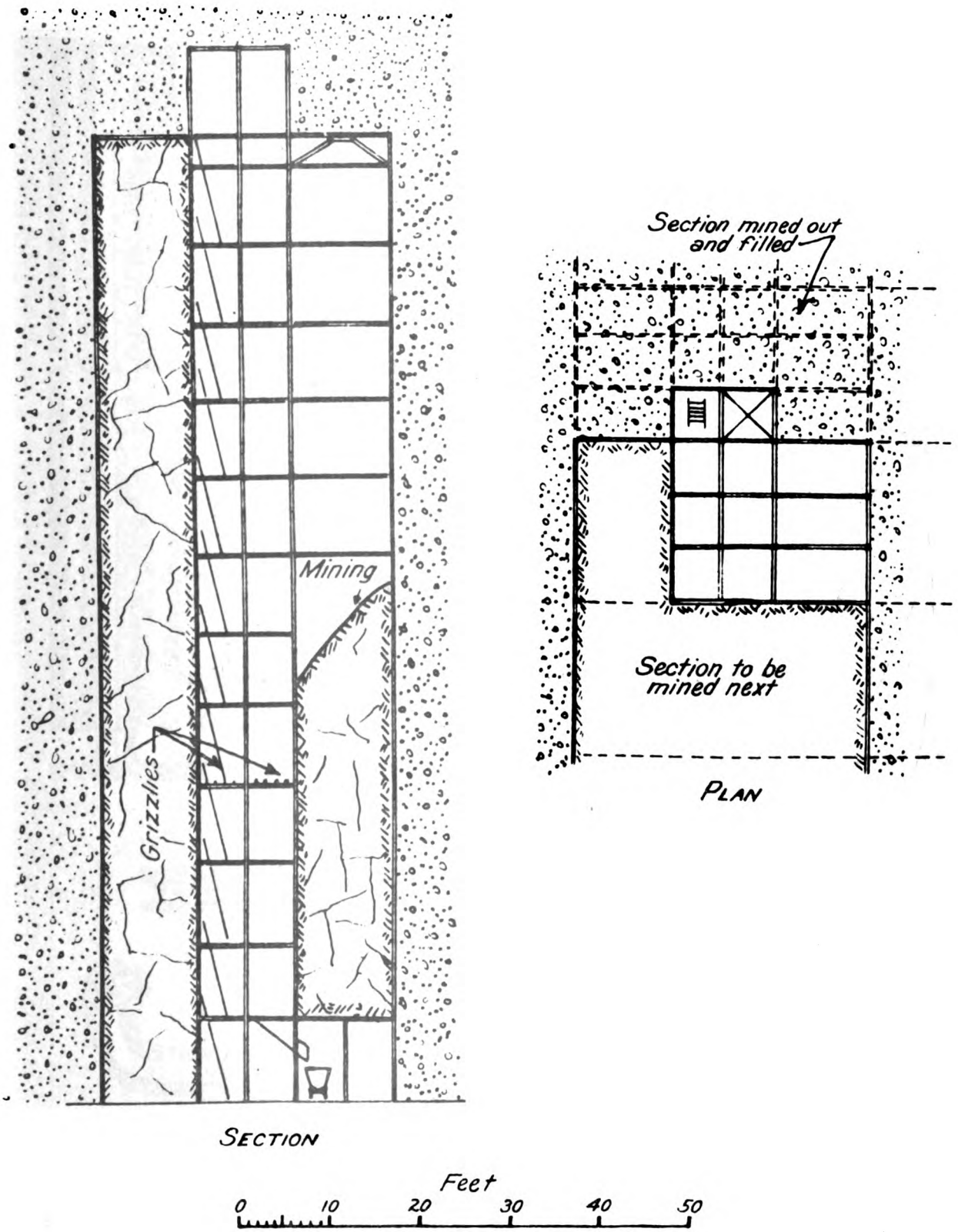

Figure 43.- Method of mining crushed pillars at the United Verde Extension mine

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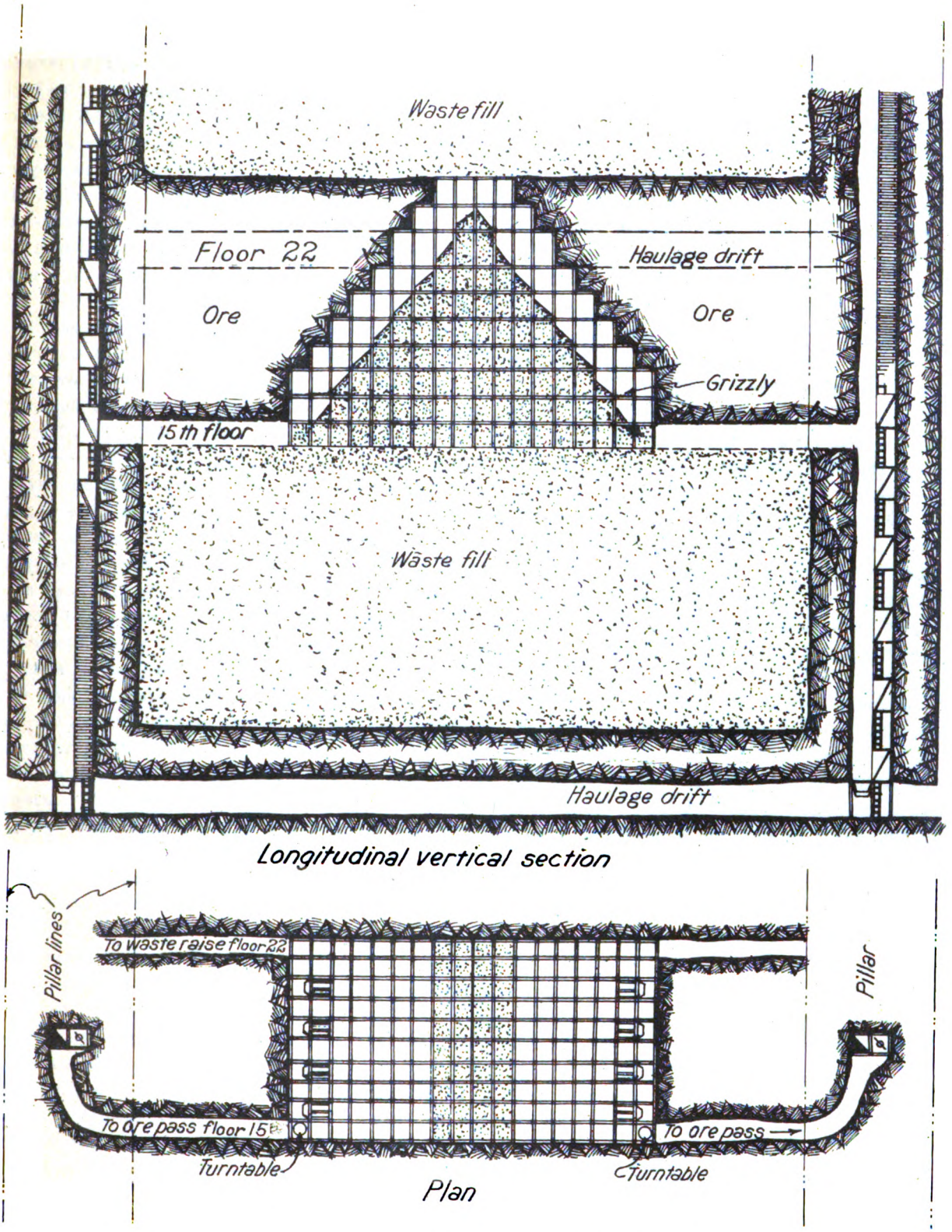

Figure 44.- Inclined square-set method of mining horizontal pillar, United Verde mine

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hambre[18] if there is no haulge drift in the footwall of the stope, one is drven before he pillar is removed.

Crown pillars of cut-and-fill or shrinkage stopes usually are taken out by methods similar to those used for removing corresponding sections of straight square-set stopes (see descriptions of methods used at Tintic Standard, Hecla, and Morning mines). Crown pillars at the tops of cut-and-fill stopes at the United Verde mine are mined by a rill method of square-setting (fig. 44).[19] The main advantages are an increased tonnage from a given area, and a lower cost per ton as compared with horizontal square-setting. It also has the advantage that there is less weight in the brow, since there is no large square brow at any place. The only serious disadvantage is the difficulty in sorting.

At the United Verde mine square-set stoping is started from a raise from the center of the cut-and-fill stope below. Four rows of sets on the second and two on the third floor usually are taken out before any fill is introduced. After the incline is established, stoping on each new cut is started at the bottom and progresses upward to the crest. One side of the rill is mined while the other side is being filled. The mining procedure is similar to that for any other square-set stope; the only additional precaution necessary is that more care must be exercised in the side blocking to prevent the side thrust of the waste from causing a side movement and distortion of the sets. The waste is confined to a steeper angle than its natural angle of repose. The greatest contributing factor to the success of this stoping method has been the way in which the floor has been placed and the waste introduced. This is shown in Figure 20. The floor is placed at a slightly steeper angle than the angle of repose of the waste, so that when the waste is dumped in at the crest, little or no tamping of waste under the floor is necessary. Under the caps there are occasionally a few voids which have to be hand filled.

At the Homestake mine, as stated before, crown pillars 25 feet thick are taken out across filled shrinkage stopes by square-setting. Beginning at the footwall the filling, which after settling is 9 or 10 feet below the back, is leveled off and 6 by 8 inch by 11-foot sills are laid. The sills are framed to fit the 6 by 6 inch by 5 1/2 inch tenons of the posts. The dap on the end of the sill which is inserted under a standing post is 1/2-inch long; the other end is 5 1/2 inches long. A floor is laid on the sills. The posts of the sets standing on the fill are 1 foot longer than in a standard set. Beginning at the footwall, vertical sections three sets wide are taken out across the pillar. Temporary chutes are built in sets of the sill floor for loading the ore into cars which are pushed by hand to a rock raise in a vertical pillar alongside the filled shrinkage stope. Sets are lagged over in a checkerboard pattern to break the fall of ore and to deflect it into the temporary chutes. The line of sets next to the ore is lagged with 2-inch slabs and the section filled by tapping the fill in the finished stope above. Pulling this fill as the stope advances disturbs the filling immediately above the next section to be mined. This increases the likelihood that loose waste may break into a working section and may increase the crushing movement due to the change of equilibrium as pillars are removed. Against these disadvantages in this method of filling is balanced a cheap source of waste.

As in the vertical pillars, the ore is mined on contract. A price of $1.09 per ton for labor and explosives is paid in most of the stopes. In badly broken ground $1.24 is paid; under extremely bad conditions the price is $1.35 per ton.

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[18] – Richert, Geo. L., Mining Methods at Minas de Matahambre, Matahambre, Pinar del Rio, Cuba: Inf. Circ. 6145, Bureau of Mines, June, 1929, 18 pp.

[19] – Quayle, T. W., Mining Methods and Practices at the United Verde Copper Mine, Jerome, Ariz.: Inf. Circ. 6440, Bureau of Mines, Feb., 1931, 31 pp.

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Recovery of Caved Ground

The removal of caved ore is the most difficult of all stoping operations. Caves may occur when running ground is encountered unexpectedly or where stopes are left idle for a time. However, by the selection of the proper mining method and by following good practice, such caves are not likely to happen.

The caved ore may be removed and the ground caught up by one of two methods—underhand mining, or the use of spiling. The first method is used where a raise and drift is open and the ore can be attacked from the top; the second where it can only be reached from a side.

In catching up the ground by underhand stoping the practice is similar to that for mining running ground by downward vertical slices. However, in caved ground the walls may be broken and the ore is likely to be mixed with wall rock. In such cases the stope timbering must be blocked to solid ground, which may require considerable shoring up or bulkheading.

In mining downward, breast boards are used for holding back the loose material. Stringers with stulls or "boom" sets (fig. 38) are used for supporting the timber in place while space is being made underneath for the next set. Where in some cases the walls are not caved they may be supported by stulls and caps as mining progresses downward.

On the Mother Lode of California[50] underhand stoping from the level has been successfully applied to caved blocks of ore, which could not otherwise be recovered economically (fig. 45). Vertical slices of the ore are taken downward, the ore running by gravity to the chute of the raise from which the work is started. Stulls, with posts between, support the walls temporarily. After a considerable area has been opened, lining is nailed to the timbers to leave working room between the lining and the ore, and waste is run into the remaining space to form an artificial pillar. Mining is then resumed and the operation repeated until the edge of the ore is reached.

The manner of recovering caved ground under a flat back in wide stopes by means of "boom" sets is shown in Figure 46, B and C.[51] The details of the boom sets are shown in Figure 46, A. Two booms of 10 by 10 or 10 by 12 inch timber 11 1/2 feet long are run out into the cavedarea below the first two caps of the sets in place back of the cave and nearest the top of the cave. One boom is used under each end of the cap, with 4 by 10 inch spreaders between to hold the booms solidly against the posts supporting the cap, as shown in the drawing. Each boom is supported by a boom post under the foremost cap and is tailed or blocked down with a 4-inch block under the next cap back. A 4-inch block is also put between the boom and the cap of the first set of timber in order to have the boom level. The length of the booms is such as to allow them to support a cap for the set ahead at the proper distance from the timber in place. This cap is also set up on 4-inch blocks in order to have it level with the other timber. Next a 4-inch lagging is laid across the two booms just behind the caps to support the two girts which are laid in place. The cap and the two girts are laced to the timbers behind and cross-laced to keep them in place. The back is caught up and held steady by cribbing on top of the cap and girts that are held up by the booms.

The set on the floor below is then placed with the booms on the pile of broken rock; the cap, girts, and the posts support the timber already in place above. Figure 46, B, shows the complete first square-set ahead into the caved area, with the cribbing holding the back. The rock below this set can be removed and other sets placed, making the timbering complete down to the bottom of the cave. The same procedure can be followed for putting in the next

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[50] – Arnot, Stanley A., Mining Methods in the Mother Lode District of California: Tech. Pub. No. 1496-A, issued with Mining and Metallurgy, Sept., 1925, 17 pp.

[51] – Bicknell, H. L., The Butte System of Square-Set Stoping: Compressed Air Mag., April, 1922, p. 115.

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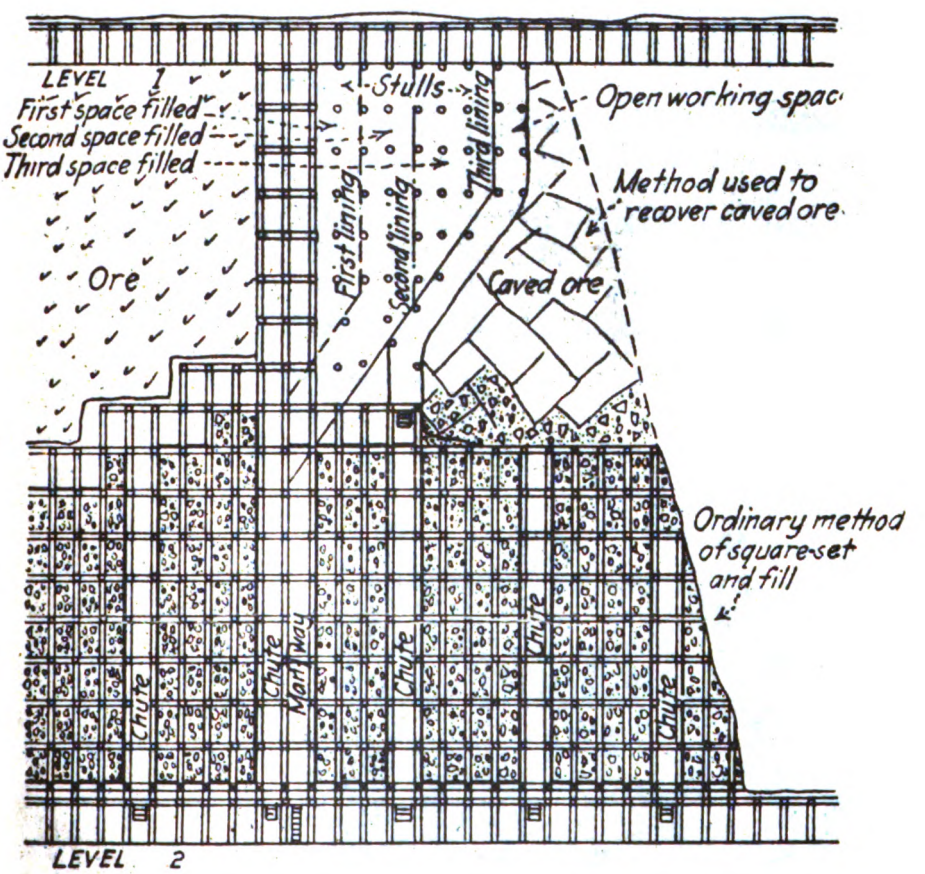

Figure 45.— Method of mining caved ore, Mother Lode district, California

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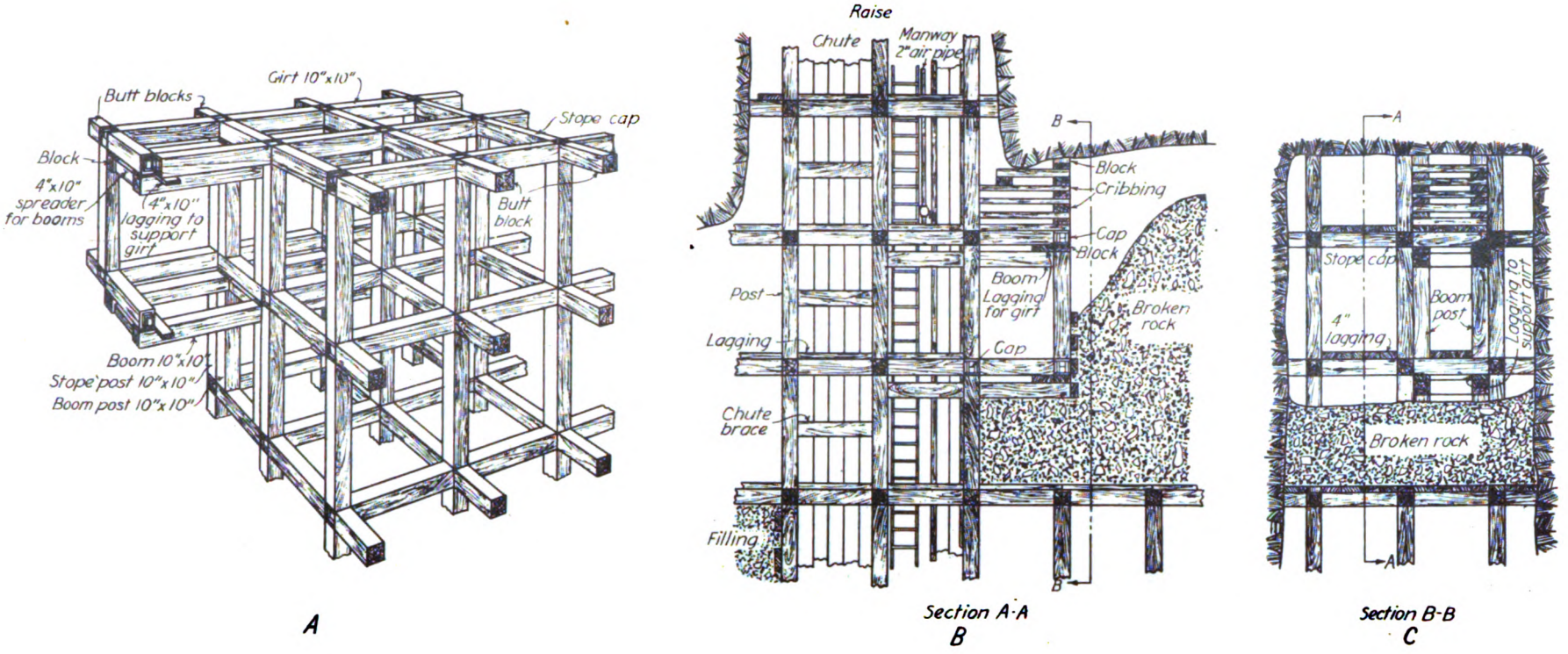

Figure 46.—Underhand stoping with booms at Butte: A, Details of boom sets; B and C, recovery of caved ground in square-set stopes

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line of sets adjacent to the first ones placed. In this way the timber can be advanced a set ahead across the stope, and then, starting ahead at one side of the stope, the whole operation is repeated until the cave has been completely timbered and the broken ore and waste have been removed.

Spiling is usually necessary for recovering ore in caved stopes or fill from old stopes which are only accessible at the side or bottom. Where a caved stope can be approached only from or near the bottom, a timbered working raise is run at the edge of the cave in solid ground. A floor is then extended to the ore as near the top of the cave as practicable. As the ground is opened up it is timbered with square-sets. The first step is to place bridging over the set nearest to the cover. Spiling is then driven into the caved ore. Bridging usually consists of two 6-inch blocks placed at each end of the cap with a 4 by 10 inch lagging laid parallel to the cap on top of the blocks. This lagging is blocked solidly to the rock above, leaving a space 6 inches in height above the cap through which the spiling are driven. Spiling are made of 4-inch timber up to 10 inches wide and up to 9 1/2 feet long; one end is sawn as shown in Figure 47. The spiling are then driven through the space above the cap at an upward angle into the caved or loose ground, usually by means of a drilling machine with a special tool in the chuck. The spiling extends over the cap more than 6 feet, which gives room for placing a complete set when the operation is complete. The upward angle is sufficient to allow bridging to be placed over the set. The first spiling is usually driven at one side of the bridging close to the bridging block at such an angle that the forward end when in place will be 6 or 8 inches beyond and above the cap and close to the wall. The remaining spiling are driven at such angles that they "fan" and form a complete covering for the set of timber to be put in place. As each spiling is driven ahead some of the broken rock is cleared away from underneath it so that if any large pieces of rock are encountered ahead of the spiling they can be barred out of the way or taken down. After the top spiling have been driven, the ground immediately underneath for about 4 feet is removed and two 6-inch I beams are hooked on the last cap (fig. 47) by heavy steel hangers. The ends of the I beams are extended forward to a point just back of where the cap of the next set will be when in position. A crosspiece is then placed across the forward ends of the I beams and brought up snugly against the spiling by blocking down the back ends of the I beams under the second cap back. The I beams support the spiling while the set is placed. The ore is then removed until room for another set is made, after which the next set is placed.

The best practice in mining caved ground is to start at the highest possible point, "catching up" the back and then working downward. This gives the miners a safe place to work, besides preventing further cave-ins.

In spiling in a narrow vein side boards and breast boards are put in place as room is made for them. Side boards are necessary only in order to hold the breast boards in place while the set of timber is being stood. In case the back of the cave slopes upwards from the timber, two or more sets can be completed; then the brow above the timber and close to the raise can be either barred down or blasted, taking care to blast lightly. The space is then timbered with square-sets connected to the raise timber; the sets are blocked or cribbed to the rock above. If the cave extends high enough, the cribbing operations are transferred to the floor above.

In wide stopes the method of working is more complicated. The lead set usually is driven along one wall at the highest point of attack. Both top and side spiling are necessary for making room for a set of timber. The top spiling is driven home first as a rule, then as the side spiling, beginning at the top, is driven and the rock removed, breast boards are used to hold the broken rock from running into the open space. The side spiling is driven at an angle on the outside of each of the posts to give plenty of room for timbering when the rock is cleaned out from in front of the standing timber.

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The broken rock in the set below can be partly taken out and booms used to support the cap, girts, and posts on the floor below. Figure 48 shows the advance of two sets next to one of the walls of the vein. In section BB the breast boards are not shown. After the two sets along the wall are complete, work is started in the next line of timber and is advanced two sets into the cave. This operation is carried across the stope until the other side of the stope has been reached. When this advance of two sets is finished, the timbers are well blocked from both walls of the stope. The process is repeated until the caved area is entirely caught up.

In most cases where a cave consists of more than a few sets, filling must be used to hold the sets steady and to prevent their collapse. Usually as the spiling is advanced into the cave the sets back are filled.

Miscellaneous Uses of Square-sets

Square-setting is used extensively and regularly as an auxiliary to other methods of mining. As stated previously, pillars in mines worked by open-stope, cut-and-fill, and shrinkage methods are frequently mined by square-set methods. In addition, unusually heavy ground such as encountered at faults is supported by square-sets.

As shown previously, square-setting may be used in conjunction with top-slicing. In sublevel caving the slices may be square-setted as broken. In cut-and-fill methods as much as 40 per cent of the stopes may be timbered with square-sets. In addition to using square-sets for chutes and raises for timbering the sill floors and extracting pillars, parts of cut-and-fill stopes may be regularly timbered with square-sets.

At the mine of the Empire Zinc Co.[52] at Gilman, Colo., a square-set aisle is carried up on either side of cut-and-fill stopes. This reduces the unsupported span of rock in the stopes and provides partitions between the waste and the ore; it also provides a tie for the stringers and trusses used in mining the 15-foot pillars left between the cut-and-fill stopes. The tops of the stopes are also square-setted. The cut-and-fill stopes are 35 feet wide and 100 to 250 feet long.

At the Calumet and Arizona mines 50-foot cut-and-fill stopes are taken out across the Campbell orebody; these alternate with 45-foot pillars. A line of lead square-sets is taken up along the pillar lines. The sets provide space for breaking bowlders and afford protection to the shovelers from falling rock.[53]

At the Magma mine, where 16-foot stopes are mined by a cut-and-fill method and 14 intervening pillars by an underhand method, the sill floors of the stopes are regularly timbered with square-sets and a row of three sets taken up on the footwall for ore chute and a manway. The ore immediately under the level above is also removed by square-setting. Where the walls are better than usual the cut-and-fill method may be modified in that 5 or 6 floors may be mined and square-setted befored filling. Also at this mine in unusually heavy ground the cut-and-fill stopes may be square-setted the full distance and each floor filled as mined.

Square-setting may be used in conjunction with shrinkage stoping as it is with the cut-and-fill method. As stated before, pillars between shrinkage stopes and crown pillars above the stopes are mined by square-setting at the Homestake mine. In this particular case 55 per cent of the ore is removed by square-setting, although the method usually is listed as "shrinkage."

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[52] - Borchert, W. O., The Empire Zinc Company's Operation at Gilman, Colo.: Eng. and Min. Jour., vol. 132, Aug. 10, 1931, p. 99.

[53] - Lavender, H. M., Mining Methods at the Campbell Mine of the Calumet & Arizona Mining Co., Warren, Ariz.: Inf. Circ. 6289, Bureau of Mines, April, 1930, 18 pp.

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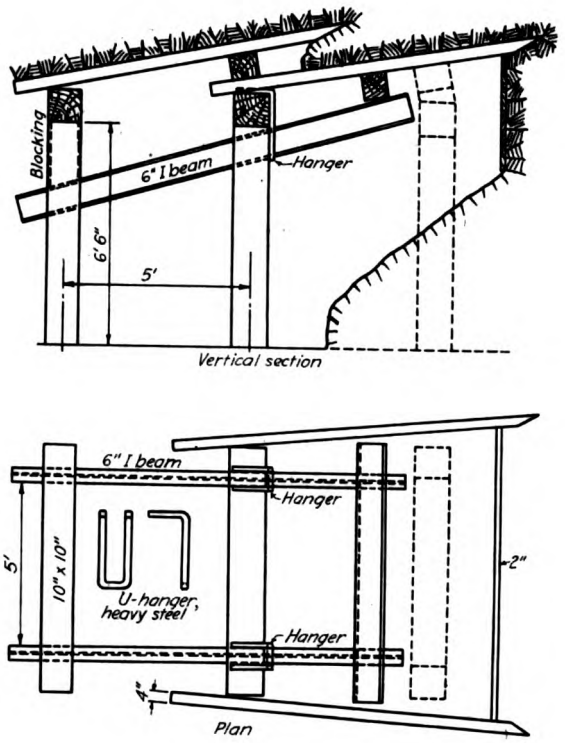

Figure 47.- Method of spiling in loose ground

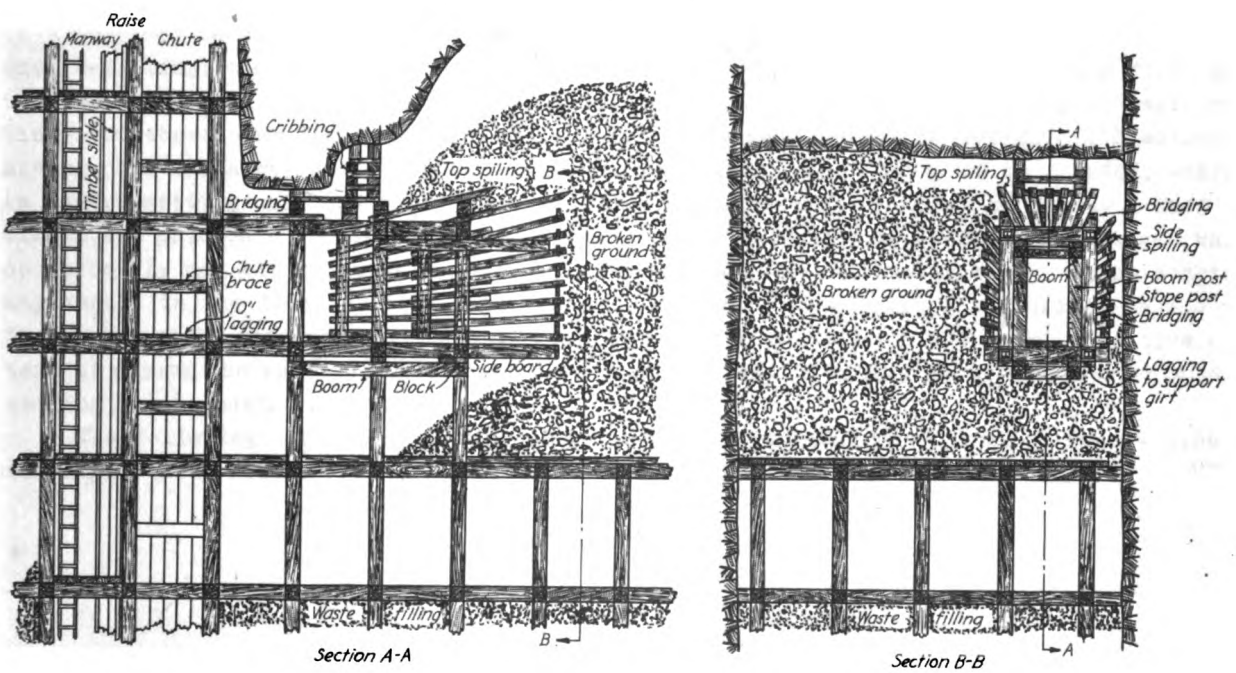

Figure 48.- Spiling as used in wide stopes for recovery of caved ground

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Ore chutes and manways in shrinkage stopes usually are either cribbed or square-setted.

Ground that can be mined by open stopes usually does not require the use of many square-sets. The crown pillars, however, may be extracted by this method. In narrow open stopes when stulls are used square-sets may be used for chutes and raises. Moreover, if heavy ground is encountered, regular square-set methods may be employed.

Only a minor amount of square-setting is done where caving methods are used. Square-sets may be used, however, to protect chutes and grizzlies in cut-off stopes and for manways and raises.

COST OF MINING BY SQUARE-SET METHODS

The cost of mining by square-set methods depends, obviously, upon many factors of which the most important is the character of the ore and enclosing rocks. Where the ground will stand until a set can be installed and does not take weight until after operations have progressed beyond the floor, regular routine procedure can be applied and relatively low costs obtained. Doubling-up sets, placing cribs, bulkheads, or booms, and driving spiling increase both the timber and the labor costs. The condition of the ground also determines how many sets or floors can be mined without filling. Lower costs can be attained when one or more floors can be taken out before filling than where it is necessary to fill closely behind the mining face.

Next to the character of the ore and walls, management and organization have a bearing on stoping costs. The method of attack and size of sections should be chosen to fit the local conditions; the number and spacing of waste raises and ore chutes should be selected to fit the size and shape of the orebody. Although square-sets, chutes, and mining details should be standardized, the general method of stoping should be flexible enough to permit variations to conform to changing conditions. One of the inherent advantages of square-set mining is the facility with which changing conditions can be met.

Better-trained men and more efficient supervision are required in square-setting than in some other methods of mining. The ground usually is heavy, else it would not be mined by square-setting; therefore, more care is needed to prevent caving or the timbering from getting out of line. This being the case, bonus or contract systems must be applied with caution, and where used the work must be closely supervised. With the cut-and-fill method of mining, for instance, all the ground that can be drilled in a shift can be blasted, whereas in square-setting only enough for one set usually can be safely broken at a time. When the miners are paid on a tonnage basis the incentive always exists to break large rounds, which occasionally may start caving. Moreover, the sets may be put in hurriedly, which practice may result in the timbers being insufficiently blocked. The limitations placed on the way the work must be done prevent the full benefit that can be derived from extra-incentive systems of paying the workmen; this gives some other systems of mining an advantage over square-setting in the matter of costs.

The following table shows comparative data of four methods of stoping at the mine of the Empire Zinc Co. at Gilman, Colo.[54]

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[54] - See footnote 52.

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Table 5.- Production, timber, and powder statistics for stoping operations, Empire Zinc Co., Gilman, Colo.

	A	B	C	D
Production per shift:				
Machineman shift.....tons	25.7	28.4	27.5	21.7
Timberman shift.....do.	13.5	21.4	41.7	18.4
Mucker shift.....do.	13.5	19.5	24.0	19.3
Fill-labor shift.....do.	35.1	44.2	-	-
Total man-shift.....do.	4.64	6.4	9.1	6.4
Timber per ton,.....board feet	13.9	7.3	3.5	6.7
Powder per ton,.....pounds	0.67	0.53	0.38	0.41

Note: A-Average for eleven zinc square-set stopes. Powder per ton includes that used in breaking waste from the back for filling. Mucking and filling by hand.

B-Average for nine zinc cut-and-fill stopes. Figures include square-setting of tops of stopes in addition to normal cut-and-fill operations. Mucking and filling in stopes largely by scraping.

C-One open stope of the low-dip type, in which back caving is allowed. The stope is not filled, and timbering is largely temporary crib supports.

D-15-foot underhand pillar stopes with truss and stringer support. Figures are based on two stopes. Tonnage involved is insufficient to give accurate data, and filling, as yet, has not been done. Mucking is by hand. Most of the ore slides direct to chutes.

Table 6 shows the relative costs of labor and explosives in representative stopes in the limestone division of the Copper Queen mine during the last six months of 1930. The average consumption of timber for top-slice and square-set stoping was 14 1/2 board feet per ton. The cost per ton was $0.40.

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Table 6.- Relative costs of labor and explosives in representative stopes in the limestone division, Copper Queen mine, during the last six months of 1930

Method used	Tons	Cubic feet	Total labor cost	Explosives cost	Total labor and explosives cost	Explosives, pounds	Cost per ton	Production per man-shift tons	Production per man-shift cubic feet
Square-se in hard ground	15,245	133,200	$14,203.73	$2,087.47	$16,291.20	8,975	$1.07	7.7	67.0
Square-set in intermediate ground	17,508	191,847	16,498.91	2,126.54	18,625.45	9,656	1.06	7.8	85.6
Square-set in soft ground	3,189	40,050	3,560.76	461.64	4,022.40	7,780	1.26	5.5	69.7
Top-slice, in hard ground	13,087	133,418	14,658.84	2,028.23	16,687.07	8,814	1.27	5.9	60.4
Top-slice, in intermediate ground	8,887	92,483	7,270.45	997.43	8,267.88	3,999	.93	8.2	86.0
Cut-and-fill, in hard ground	2,161	20,120	2,272.58	400.49	2,673.07	1,460	1.23	6.2	57.2

The following tabulation shows the average cost of both square-setting and top-slicing for 1930, exclusive of supervision and general charges, at the Copper Queen mine. An average of 13,000 tons was mined per month. The tons mined per man with straight square-set mining was 7.0, and with top-slicing, 6.8.

Cost of square-setting and top-slicing, 1930, Copper Queen mine

Labor in stopes	$1.07
Explosives cost, surface	.10
Explosives cost, handling to stopes	.03
Timber cost, surface	.30
Timber cost, handling to stopes	.10
Compressed air, drills, steel, etc.	.37
Stope preparation	.30
General development	.60
Total	2.87

At the Pilares mine of the Moctezuma Copper Co., Sonora, Mexico, square-setting was used for mining pillars between old stopes and in badly crushed areas. The following tabulation gives comparative data with other systems of mining at this mine.[55]

[55] - Leland, Everard, Mining Methods and Costs at the Pilares Mine, Pilares de Nacozari, Sonora, Mexico: Inf. Circ. 6307, Bureau of Mines, Aug., 1930, p. 24.

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Comparative data on production obtained, costs, and supplies used with various systems at the Pilares mine

System	Per cent of total mined by each method	Stope cost per ton	Timber per ton, board feet	Powder per ton, pounds	Tons per man-shift
Horizontal cut-and-fill	59.4	$1.07	3.6	0.415	4.30
Rill cut-and-fill	17.6	.91	4.2	.345	5.02
Square-set	17.7	1.62	13.6	.325	3.36
Shrinkage	1.6	.64	.15	.485	6.88
Top-slice	3.7	1.55	11.5	.286	3.95

Cost data of 19 mines using the square-set method of mining are given in Table 7.

SUMMARY

The development of the square-set method of mining was an important advance in the art of mining and made possible the extraction of orebodies in heavy ground that previously could not be mined. Later other new methods, such as cut-and-fill, top-slicing, and caving, in many instances replaced square-setting.

Stoping costs by square-set mining usually are higher than with other methods; therefore, the system is not generally used where the character of the ground permits mining by some other method. Square-setting, however, retains an important field, and orebodies that can not be mined by other methods, because of ground conditions, can be successfully extracted by square-setting. It is the principal method used in such important mining districts as Butte, Coeur d'Alene, Mother Lode, Park City, and Tintic. It is used to some extent, either as a primary or as an auxiliary method, in nearly all western mining districts.

Square-setting is especially adapted to mining relatively high-grade orebodies in heavy ground with a maximum recovery of ore, a minimum admixture of waste, and a minimum subsidence of the overlying strata. The system is extremely flexible and can be varied to meet changing conditions.

Because of the widely differing conditions met in orebodies mined by square-setting, considerable variation exists in the manner of attack. Running or very loose ground would very likely be mined by downward vertical slices. If the ore has just sufficient strength to stand over a short period, or the ground pressure is largely from the top, upward vertical sections would probably be mined. In still stronger ore or where the pressure is from the walls, horizontal or rill sections would be taken. In a narrow vein horizontal sections would be taken. In wide veins either horizontal or vertical sections would be mined, depending on the ground conditions; the present tendency, however, is toward the use of vertical slices.

Except in a few instances where the square-sets are used primarily to provide working platforms from which the men may reach the back, further support is afforded in all square-set stopes by filling with waste rock.

The size of the sections mined and how closely filling must follow stoping are governed by ground conditions.

Production of ore in square-set stopes ranges from 2 to 7 tons per man-shift. Timber consumption usually is from 10 to 15 board feet per ton or ore, and between 1/2 and 1 pound of explosive generally is used per ton of ore stoped. Stoping costs at mines discussed in this paper range from $1.20 to $5 per ton; the average, however, is between $2 and $2.50.

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Table 7.- Cost data on representative mines using square-set methods of mining

Mine	Period	Mined, tons	Tons per man-shift		Timber per ton (total mining), board feet	Explosives per ton, pounds		Ore per foot of development, tons	Costs per ton of ore	
			Stopes	Total mining		Stopes	Total mining		Stopes	Total mining
Anaconda	-	-	5.05	1.82	22.05	-	1.07	18.0 (1927) 14.2 (1926)	-	-
Argonaut	Sept., 1929	7,800	2.78	1.92	11.48	0.93	1.01	26.8	[1] $2.439	[1] $3.991
Page	1928	90,460	3.60	2.90	13.09	.65	1.41	19.0	2.150	[2] 3.820
Pecos	1929	217,121	1.70	1.41	10.40	-	.73	16.3	[3] 2.83	4.898
Central Eureka	Sept., 1930	4,143	-	1.76	25.78	-	1.01	17.8	-	-
Black Rock	Nov., 1929	15,929	[2] 2.81	[2] 1.70	27.55	-	1.73	-	-	-
Hecla and Star	1928	312,942	[2] 6.07	3.90	19.46	.53	1.48	-	1.21	3.297
Morning	1928	276,890	-	1.92	12.75	.59	.96	65.8	2.371	4.245
Silver King Coalition	1929	180,204	2.12	.99	($0.34)	1.29	3.61	5.4	3.502	7.745
Ground Hog	Jan.to March, 1930	11,146	3.74	1.19	8.74	.63	.90	-	1.762	3.990
Ground Hog	1930	46,253	-	-	-	-	-	13.2	2.34	[4] 3.86
Park Utah	1928	192,250	3.18	2.03	16.46	.78	1.53	15.7	2.426	4.662
Cananea (Colorada mine)	Jan. to July, 1929	262,278	-	1.83	7.19	1.06	1.37	-	[1] 1.203	[1] 2.441
Bunker Hill and Sullivan	1928	452,345	($1.419)	$1.627)	($0.321)	-	($0.167)	124.6	2.414	[5] 3.897
Old Dominion	1928	350,661	[6] 5.70	[7] 1.89	-	[8] .28	[8] .28	-	-	-
Tintic Standard	Nov., 1929	8,758	2.41	.96	25.51	.42	1.07	-	4.973	9.484
United Verde	1929	-	[6] 2.45	-	[6] 12.52	[6] .60	[9] 1.05	[10] 28.7	-	-
Copper Queen	July to Dec., 1930	725,409	6.8	-	14.5	.67	-	14	2.17	-

[1] - Supervision and indirect cost excluded.
[2] - Surface labor chargeable to underground mining excluded.
[3] - Square-set mining only.
[4] - Trucking to custom mill, general overhead, and salaried employees excluded.
[5] - Development work and surface labor chargeable to underground mining excluded.
[6] - Square-set stopes only.
[7] - All methods, including development.
[8] - All methods, excluding development.
[9] - Development figures computed against total stope tonnage.
[10] - For entire mine, not segregated according to mining methods.

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